African smallholder farmers: rice production and sustainable livelihoods

J.C. Norman [a] and B. Kebe [b]

[a] *Professor, Department of Crop Science, University of Ghana, Legon, Accra, Ghana*

[b] *Plant Production Officer, FAO Regional Office for Africa, Accra, Ghana*

The theme *Rice is Life* was adopted to implement the International Year of Rice (IYR) 2004, declared by the United Nations General Assembly during its 57th Session. One major objective of IYR was to focus attention on the role that rice could play in providing the population with food security and addressing poverty alleviation. Other issues included sustainable development, preservation of cultural heritage and biodiversity, scientific cooperation and economic policy.

Rice is the staple food for many Africans and constitutes a major part of the diet for many others. During the past three decades, the demand for rice has increased steadily, playing a major role in the strategic food security planning policies of many countries.

With the exception of a few countries which have attained self-sufficiency in rice production, rice demand exceeds production in most countries and large quantities of rice continue to be imported to meet domestic demands at a huge cost in foreign currency (Table 1).

In Ghana, for example, rice imports increased from US$100 million in 1999 to US$200 million in 2005 when national rice demand rose to 700 tonnes.

Africa's inability to achieve rice self-sufficiency is the result of major constraints in the entire chain of the rice production industry. It is necessary to minimize over-reliance on rice imports for meeting increasing domestic demands. Local resources and strategies should be exploited at all levels of the rice industry to promote increased rice crop production.

TABLE 1
Rice imports to and exports from sub-Saharan Africa, 2002

Region	Imports (*million US$*)	Exports (*million US$*)
West Africa	92 756	1 856
East Africa	8 198	292
Central and southern Africa	30 989	785
Northern Africa	3 156	10 556
Africa	**135 099**	**13 489**

Source: FAO, 2004.

This paper presents an overview of rice production in sub-Saharan Africa (SSA) and discusses the importance of rice to smallholder farmers. The paper further describes the impact of the application of appropriate rice production technologies, through the introduction of integrated production pest management (IPPM) and farmer field schools (FFS) by FAO into African smallholder rice production systems as a mechanism for promoting sustainable and increased rice production to improve the rural lives of the farming communities.

OVERVIEW OF RICE PRODUCTION IN SUB-SAHARAN AFRICA

In sub-Saharan Africa, rice is produced in five main ecosystems, namely rainfed uplands, rainfed lowlands, inland swamps, irrigated ecosystem and mangrove swamps.(Norman and Otoo, 2003).

Rice production in sub-Saharan Africa

In 2003, Africa produced about 15.08 million tonnes of paddy rice on 10.23 million ha – 3.3 and 6.11 percent of the world's total rice production and rice area, respectively.

- West Africa accounts for 70.4% (approx. 8.74 million ha) of rice area. The major contributing countries are Nigeria (47.9%), Guinea (5.20%), Côte d'Ivoire (5%) and Mali (4%).
- East Africa accounts for 16.1% of rice area. The major contributing countries are Tanzania (6.0%) and Madagascar (3.19%).
- Central and southern Africa account for 7.5% of rice area. The major contributing countries are Democratic Republic of the Congo (4.05%) and Mozambique (1.8%).

TABLE 2
Paddy rice production (*million tonnes*) in the regions of Africa

	1997	2003	Change	Regional contribution (%)
North Africa	5.38	5.54	+0.16	29.1
West Africa	7.05	8.74	+1.69	45.8
East Africa	3.66	3.63	-0.03	19.1
Central and southern Africa	0.58	1.17	+0.59	6.2
Africa	**16.67**	**19.08**	**+2.41**	

Source: FAO, 2000 and 2003.

TABLE 3
Rice yield (*tonnes/ha*) in different regions of Africa

	1997	2003	Change
North Africa	8 431	n.a.	-
West Africa	1 610	1 906	+296
East Africa	1 884	2 294	+410
Central and southern Africa	865	1 732	+867
Africa	**2 186**	**1 865**	**-321**

Source: FAO, 2000 and 2003.

In Mozambique, the smallest of the principal contributors, cultivation is mostly by smallholders with an average area of less than 0.5 ha. It is estimated that at least 500 000 farming families (about 2.5 million people) are directly involved in rice production. Women provide most of the labour force for rice production.

Paddy rice production in Africa is presented in Table 2. Rice production area increased steadily from 1997 to 2003, with a total increase of 2.61 million ha in 6 years. Regional area trends indicate that between 1997 and 2003, West Africa saw the greatest improvement in terms of area compared to the other four regions, which showed insignificant changes.

Paddy rice production in Africa increased from 16.67 million tonnes in 1997 to 19.08 million tonnes in 2003, corresponding to the increase in area over the same period. Regional production trends indicate that West Africa had the greatest increase in production among the five regions between 1997 and 2003. The four remaining regions show only slight changes in production over the same period. (FAO, 2000, 2003) (Table 3).

Rice production and grain yields in smallholder farmer production systems

The average paddy production and grain yield obtained by smallholder farmers in Africa (1.87 tonnes/ha) is well below the world average (3.84 tonnes/ha) (Table 3). The low grain yield is due to several factors, including the low standard of production technologies used and the predominance of cultivation in upland agro-ecosystems (55 percent). The irrigated ecosystem represents only 11 percent of the total rice area in Africa, while worldwide it accounts for 53 percent (Kaung Zan, John and Alam, 1985). Average grain yield in Africa shows very little improvement with time. North Africa has the highest grain yield because of the high level of production technology and the dominance of the irrigated ecosystem.

West Africa and East Africa have the lowest average grain yields in Africa (1.9 and 2.3 tonnes/ha, respectively). It should be noted that West Africa (which contributes 70.4 percent of the rice area) accounts for 45.8 percent of total production, while North Africa (6.7 percent of the rice area) accounts for 29.1 percent of total production because of the higher grain yields, higher cropping intensities and the dominance of the irrigated ecosystem. The low productivity of farmers' fields is due to several constraints, including:

- high incidence of pests, weeds and diseases;
- drought and poor water control;
- poor seed management;
- poor soil fertility management;
- lack of access to credit, farm inputs, farm machinery and animal traction; and
- shortage of labour.

Rice production faces other constraints (Oteng, 1994; Misari, 2002; AAG, 2004; OXFAM, 2005), including:

- late planting;
- poor post-harvest handling, processing and marketing;
- poor extension services;
- inadequate rural infrastructures; and
- ineffective farmers' organizations.

The situation in SSA calls for the intervention of science and technology and socio-economics, possibly with the technical assistance of FAO, to significantly improve production practices.

RICE IN THE RURAL ECONOMY OF AFRICAN SMALLHOLDER FARMERS

Rice as a staple food

Rice is rich in carbohydrates and proteins and is used mainly for human food consumed in the form of whole grains. It provides more calories and protein than cassava, maize or sorghum/millet. Rice forms the basis of the diet of millions of people in SSA. Over 90 percent of rice is eaten in the form of various cooked preparations. Rice is usually cooked by boiling in water, steaming or frying, and is eaten with beans, gari, vegetables, fish and meat or with stews. It is also eaten in the form of parched rice, rice flour, rice flakes, puffed rice and rice pudding. Rice flour is used in confectionery, rice-cream, pudding and pastry.

Rice forms an integral part of religious ceremonies, festivals and holidays. In Sierra Leone, West Africa, for example, rice is the preferred staple and is central to Sierra Leone's economy. Rice plays a significant role and is an integral component of the economic and social order within the rural community. Furthermore, the rice sub-sector is highly sensitive to movements in the exchange rate and has strong implications for the balance of payments. Rice is generally accepted as a medium of exchange and it drives the barter economy, often being used to procure coffee and cocoa, lure labour, and purchase farm inputs and wage goods.

Rice for food security

Food security has been defined as "access by all people at all times to enough food for an active healthy life". Food security at household level is also important for ensuring a good livelihood and freedom from hunger. In countries where rice is the staple food it plays a very important part in food security and socio-economic development.

As a food crop, rice has some inherent characteristics which make it attractive, in particular for small-scale farmers as well as for the urban poor and rich:

- It is rich in carbohydrates that provide energy.
- It is available all year round because of its long shelf-life, making it preferable to other crops for food security.

Rice consumption is becoming increasingly popular in many countries in SSA, where rice is not traditionally a major food crop, for example, Benin, Burkina Faso, Cape Verde, Ghana, Guinea, Mali, Niger and Togo (Tshibaka and Klevor, 2002).

In Mozambique, rice is consumed all over the country and constitutes a basic staple for a significant part of the population. Rice consumption increased by 8 percent per annum between 1995 and 1999. While cereals contribute 61 percent of the energy supply to the rural population, rice provides 54 percent of their energy needs. Rice forms the basis of the diet and is grown by more than 95 percent of rural families.

A combination of factors influences the increase in rice consumption. Urbanization is one the major factors causing the shift in consumer preference towards rice. Rice dishes are comparatively easy to prepare compared to other traditional cereals, such as sorghum, maize and millet, thereby reducing the work involved in food preparation. Rice, therefore, fits easily into urban lifestyles, which tend to be crowded with a multitude of time-consuming activities.

Rice for poverty reduction

Rice production is a major source of employment, income generation and nutrition in many poor food-insecure countries in SSA. The numerous activities provide employment to millions of people who work either directly in rice production or in related support services. After harvesting rice, farm activities shift to post-production operations, namely harvesting, threshing, drying, milling, storage and trade. The preparation of milled rice for consumption, the transformation of milled rice to other products, and the utilization of broken rice, rice bran, rice hulls and husks, and rice straw provide additional employment opportunities for a large number of people. In Nigeria, for example, rice is usually parboiled before hulling. These operations are typically done using small-scale equipment, generating substantial post-harvest activity in rural and secondary urban areas (Misari, 2002).

The income generated from rice cultivation and post-harvest activities provides cash to cover the expenses of clothing, housing, education and other social activities of the majority of people in rural areas. In countries, such as the Gambia, Guinea and Madagascar, sustainable rice production is the key to the improvement of rural livelihoods, not only of small rice farmers but also of poor families in urban centres.

APPLICATION OF SCIENCE AND TECHNOLOGY TO RICE PRODUCTION: INTRODUCTION OF IPM STRATEGIES FOR IRRIGATED RICE PRODUCTION

The adoption of improved rice production and processing technologies developed through the application of science and technology has been shown to guarantee the increased and sustainable production of rice. This forms the fundamental basis of FAO's technical assistance designed to move smallholder farmers away from heavy dependence on chemical pesticides for rice production, so that they may adopt the IPM approach to achieve increased and sustainable production of rice through sensible, need-based use of inputs, including pesticides. The farmer field school environment provides a unique opportunity to successfully introduce new and relevant rice production technologies through the farmer participatory approach.

In 1995, FAO and the Global IPM Facility first introduced integrated pest management (IPM) strategies for rice production in West Africa through a series of three TCP (Technical Cooperation Programme) projects sited in Ghana, Côte d'Ivoire and Burkina Faso. In all countries, field activities were conducted in close collaboration with the extension service of the Ministry of Agriculture with technical inputs from national rice scientists, international research scientists and training specialists from the Africa Rice Center (WARDA). Rice IPM programmes were later extended to Mali and Senegal, where several smallholder rice farmers were trained in the application of IPM in rice production. In Ghana, the first season-long training of trainers (TOT) was held and three farmer field schools were organized at the Dawhenya irrigated rice perimeter, with the assistance of experienced rice IPM master trainers from the Philippines National IPM Program and from FAO. TOT participants included 28 extension agents from Ghana, Côte d'Ivoire and Burkina Faso. The Dawhenya training was followed by additional training of farmers on rice IPM in irrigation sites at Afife (Volta region), Ashaiman and Dawhenya (Greater Accra region), Tongo (Upper East region) and Bolgatanga (northern region). Further development of IPM training in Ghana continued from 1997 to 2001, with financial support from UNDP under the National Poverty Reduction Program in Ghana and with technical supervision from FAO and the Global IPM Facility. At the end of this programme, a total of 1 085 rice farmers had been trained on IPM methods of sustainable rice production.

Outcome of IPM training on rice production in West and East Africa

West Africa

Training activities have successfully built national and regional capacities in national agricultural extension services and rice farming communities in integrated production and pest management (IPPM) approaches for sustainable rice production. IPPM training capacities have also been developed in the extension service and among rice farmers. IPPM knowledge and skills acquired from the rice production systems are being applied to the successful production of other crops. Interaction with farmers in all countries where IPM practices have been adopted for rice production showed that significant increases in irrigated rice yields were obtained from rice fields where IPM methods were adopted (3.74 tonnes/ha) compared with yields from farms with conventional farmers' practices. (3.6 tonnes/ha).

By adopting IPM, farmers in Dawhenya, Ghana were able to achieve lower production costs because they did not purchase pesticides (not used in rice production when farmers adopt the IPPM method). Higher rice yields under IPPM were obtained as a result of better crop management and attention to good soil amendment. Consequently, average net returns were 32 percent higher in IPM fields and pesticide use was reduced by up to 95 percent. At the irrigation site in Asutsuare, Ghana, farmers who adopted IPM practices obtained rice yields of 5.8 tonnes/ha – compared to 3.0 tonnes/ha by farmers who maintained conventional practices. By adopting IPM, farmers were able to almost double irrigated rice yields.

Results consistently show that the widescale adoption of IPPM practices has good potential for helping farmers to obtain high rice yields and achieve national food security. The success achieved with IPPM in rice production is based on the principle that sustainable food production depends largely on how well farmers can understand their farming agro-ecosystems and how efficiently they can manage their crop production environments and conserve the natural resource base. Through these efforts, FAO has helped West African countries set the stage for the rice farming community to substantially increase rice production and for rice farmers to increase their household incomes. However, this goal can only be achieved if appropriate actions are taken to promote and support national IPPM policies and programmes. Experience – especially in Mali and in Ghana (with the national ICPM [integrated crop and pest management] programme) – has shown that national IPPM policies provide a sound political framework for the establishment of and support for successful implementation of such programmes. It is vital that any proposed programme activities for rice production in the ECOWAS (Economic Community of West African States) subregion address the issue of national IPPM policies and programmes (M'Boob and Youdeowei, 2002).

East Africa – Increasing rice production in Tanzania-Zanzibar

Table 4 presents the results of the impact of IPM on rice production during a 15-year IPM project in Tanzania/Zanzibar, "Strengthening the Plant Protection Division of Zanzibar" (1983-1998), funded by the Government of the Netherlands. The data show conclusively that smallholder farmers obtained significant increases (up to 100 percent) in irrigated and upland rice yields. Through adopting IPM practices, farmers are able to address the problems of food insecurity and poverty by increasing farm incomes (Youdeowei, 2004).

In addition to increases in crop yields and farm revenue, other effects included increased self-determination, self-esteem and a sense of ownership.

ROLE OF WOMEN IN SMALLHOLDER RICE PRODUCTION

In many West African countries, women play a significant role in rice production, through which they earn a substantial proportion of their living. For example, the Irrigation Development Authority in Ghana reported that women are engaged in both pre-harvest and post-harvest operations (Lamptey, personal communication, 2006). The small-scale irrigation project implemented by GIDA (Ghana Irrigation Development Authority) estimates that about 60 percent of rice-farming activities are undertaken by women. Pre-harvest operations performed predominantly by women include the following:

- Transplanting. Women are engaged in removal of rice seedlings in the nursery, carting them from the nursery to the plot and actual transplanting; this is especially the case of women in the northern sector of Ghana.
- Manual weeding. In northern Ghana, groups of women are contracted to perform this activity.
- Bird scaring. Women are often assisted by their children in this task.
- Harvesting. In the northern half of the country, harvesting is done mostly by women, using sickles.

Post-harvest operations carried out mainly by women include packing, threshing, carting, drying, parboiling, winnowing, milling, storage and marketing.

The role of men is mostly limited to land preparation and cutting of rice stalks during harvesting. In the upper west region of Ghana, rice is normally cultivated as a commercial crop and not for family consumption. Rice is produced by women; the few men engaged in rice farming undertake land clearing, ploughing and harrowing operations. Seed sowing, transplanting, fertilizer application, weeding, harvesting and post-harvest operations are carried out only by women.

In a study examining women's role in the various stages of rice production in the Tamale District of Ghana, it was reported that women were predominantly engaged in seed sowing, fertilizer application and harvesting. Men, on the other hand, were involved in land clearing, ploughing, harrowing and weeding. Tables 5 and 6 show details of the survey data (Minnow, 1977).

STRATEGIES FOR PROMOTION OF INCREASED AND SUSTAINABLE RICE PRODUCTION IN AFRICAN SMALLHOLDER CROPPING SYSTEMS

Numerous strategies can be adopted to promote rice production in smallholder cropping systems, focusing on, for example:

TABLE 4
Impact of IPM training on rice yields and farmer income in Tanzania/Zanzibar

Crop	Yield before IPM (*tonnes/ha*)	Yield after IPM (*tonnes/ha*)	Yield increase	Effects
Irrigated rice	1.5-3	3-4 kg	100%	Increased food security, surplus may be sold
Rainfed rice	0.8-2.2	1-4 kg	20-80%	Increased food security, surplus may be sold

TABLE 5
Role of women on mechanized rice farms in Tamale District

Operation	Average percentage of total
Land-clearing	8.30
Ploughing	0.00
Harrowing	0.00
Weeding	13.79
Harvesting	51.04
Broadcasting of seeds	66.97
Broadcasting of 15-15-15	72.61
Broadcasting of sulphate of ammonium	75.03

TABLE 6
Role of women on traditional rice farms in Tamale District

Operation	Average percentage of total
Land-clearing	8.30
Ploughing	0.00
Harrowing	2.54
Weeding	19.32
Harvesting	93.05
Broadcasting of seeds	93.08
Broadcasting of 15-15-15	74.19
Broadcasting of sulphate of ammonium	88.46

- access to credit and restoration of input subsidies;
- improving labour availability;
- improving crop production and post-harvest technologies;
- improving extension services and research;
- strengthening of farmers' organizations;
- advertisement of local rice; and
- collaboration among stakeholders.

Governments must develop appropriate national rice policies which play a positive role in sustainable rice production. National rice policies should provide the framework for developing solutions to production constraints associated with technical, socio-economic and macro-economic issues, including credit and farm infrastructures, post-harvest technologies (especially for women) and support for research and extension services for technology, generation and transfer.

Access to credits

Access to credits is vital to rice farmers who require capital for:

- hiring farming equipment;
- purchasing pesticides, high quality seed, fertilizer and small-scale irrigation equipment; and
- paying for the usage of irrigation facilities for efficient water control.

Rice farmers should negotiate credit through farmers' associations. Improved seed and credit can also be made available to farmers by NGOs (non-governmental organizations), such as ActionAid, World Vision and Winrock International, that are active in the implementation of food security programmes in Africa.

Farmers' associations must continue to advocate for the restoration of subsidies for farm inputs to reduce the high cost. This would lead to increased use of inputs by farmers, and consequently higher rice productivity.

To create easier access to farm inputs, it is suggested that governments or the private sector should establish multipurpose farm input centres in each farming community for the supply of seed, fertilizers and pesticides, and for hiring farm machinery.

Labour availability

Farmers should encourage their children to stay with them in rural areas and work on farms. Governments should intervene by making life more comfortable in rural areas through holistic rural development, such as provision of potable water, electricity, road networks and community service centres.

Improving crop production and post-harvest technologies

In addition to increasing rice yields, farmers must strive to produce high quality rice in order to compete favourably with imported rice. This can be achieved by adopting and planting improved rices such as NERICA (New Rice for Africa), developed at WARDA in West Africa (Jones and Wopereis, 2001) for rainfed upland ecologies, as well as adopting improved crop production and post-harvest technologies. NERICA rice varieties are characterized by their high yields, weed competitiveness and disease-, pest- and acid-tolerant properties. In addition, the taste, aroma and cooking characteristics of NERICA compare favourably with imported rice.

Farmers must adopt one of the newly developed rice integrated crop management (RICM) technologies to improve and increase rice productivity, for example:

- FAO's IPPM and FFS approach (M'Boob and Youdeowei, 2002);
- the RiceCheck system tested in Australia (Singh, 2003); and

- WARDA's integrated rice management (IRM) in irrigated systems in the Sahel (Defoer *et al*., 2003).

Threshing on the soil results in a high percentage of stones and other foreign matter mixing with the rice. Farmers should therefore be assisted in the use of mechanized threshing in order to reduce labour and prevent the rice from being adulterated with other materials. In order to obtain high-quality rice, milling machines with special components, including de-stoners, spare parts and sieves, must be used. The machines remove stones and other foreign matter from the rice. The private sector must invest in rice processing. Development agencies, NGOs and possibly governments must support rice millers financially or provide them with milling machines to mill high-quality local rice that would compete favourably with imported rice.

Rice research and extension services

Research institutions in various African countries working on rice must be adequately supported by their governments to undertake demand-driven research on rice. The research agenda must be set by the rice farmers' organizations together with other stakeholders, such as millers, traders and consumers.

Research institutes should continue to collaborate with WARDA and other international advanced research organizations as well as foreign institutions working on rice, for example, ARIs (advanced research institutes), universities of the north and Chinese agricultural missions, to generate new technologies to increase rice productivity.

National governments should invest more in rice research. Research must focus on:

- rice production problems;
- introduction and evaluation of NERICA varieties in all rice ecologies; and
- generation of demand-driven technologies.

At subregional and regional level, the NARS (National Agricultural Research Systems) should continue to collaborate with the IARCs (International Agricultural Research Centers), in particular with WARDA and IRRI (International Rice Research Institute). WARDA is currently the major IARC promoting rice research and development in SSA through its taskforce activities (WARDA, 1998). Subregional organizations such as ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa), CORAF (West and Central African Council for Agricultural Research and Devel-opment) and SACCAR (Southern Africa Coordinating Center for Agricultural Research), and the regional body, FARA (Forum for Agricultural Research in Africa), should source for funding of rice research.

Farmers need efficient agricultural extension information to enable them to produce efficiently and increase local rice production. In addition to English, the extension information must be in the local language to ensure the widest publicity of research recommendations. It is therefore necessary for governments to provide adequate resources to the national agricultural extension services and to facilitate the work of private, NGO or FBO (farmer-based organization) extension services to produce rice extension materials in the local languages. Farmers would then be knowledgeable enough to adopt the new production and post-harvest technologies that are introduced by extension agents.

Formation/strengthening of rice farmers' organizations

Farmers' organizations have a crucial role to play in rice promotion. Existing rice farmers' organizations must be supported and where they do not exist, they should be formed. The farmers' organizations can also set their agenda for rice research with relevant research institutions. They should also be able to access market information and disseminate this information to farmer groups and organizations in order to improve access to local rice markets. In countries where rice farmers' organizations already exist, they should be strengthened by resources and training so that they might enhance their performance. Governments, NGOs and aid agencies must be encouraged to continue to provide technical support to farmers' organizations.

Production and promotion of local rice

Each country should identify a series of high-quality rice varieties that are appropriate for different rice-growing ecologies, and promote production by smallholder farmers to meet local demand. In order to promote the consumption of local rice, farmers' organizations must advocate for governments to adopt a policy of drastically reducing rice imports and increasing tariffs on imported rice. The experience in Ghana in the 1970s and Nigeria in 1989 of banning rice importation demonstrates the positive impact of such policy actions on domestic rice production (Fagade, 2001).

Locally produced rice should be well packaged to be attractive and eye-catching. Farmers would thus be encouraged to increase their investment in rice production to meet the increased demand. For effective distribution of rice, a well-organized countrywide distribution network for local rice must be established, with the active participation of the private sector, especially in terms of providing market outlets for local rice.

Local rice consumption can be introduced to schoolchildren through the NEPAD (New Partnership for Africa's Development) School Feeding Programme, which provides one good meal a day to schoolchildren. Boarding educational institutions, the security forces, hospitals, hotels etc. should also be encouraged to patronize local rice.

Collaboration of stakeholders

All stakeholders in the rice industry, including farmers, the private sector (millers, wholesalers and traders, importers), consumer organizations, governments (at district, regional and national level), NGOs and aid agencies, should be involved in national strategies for the promotion of local rice production and consumption. Each stakeholder must play its role. For example, NGOs and aid agencies must support farmers, the extension services, research, farmers' organizations, processors, and infrastructure development. The private sector should be more involved in the seed industry to promote local rice production, processing and marketing.

Provision of rural infrastructure

Functional infrastructure must be provided in rural areas to facilitate rice production, processing, storage, marketing and utilization. At national level, governments must devote more of the AGDP (agricultural gross domestic product) to the provision of rural infrastructure, such as rural road networks, small-scale irrigation facilities in upland ecologies, good rice-milling equipment, electricity, potable water and other social amenities.

The private sector must be given incentives to provide the processing equipment. At subregional and regional level, infrastructures, such as roads and storage facilities, can be provided by collaboration among countries in the subregion.

Markets

Subregional and regional markets, such as the West African Grain Market (under development), should be exploited to market rice produced by smallholders. This will promote intraregional trade in rice to satisfy the subregional rice demands and increase farmers' incomes. National markets should be integrated into consolidated subregional markets. Tariff and non-tariff barriers to facilitate the free movement of products and people between countries must be removed. Phytosanitary regulations must be harmonized to make them compatible with trade agreements related to agriculture under the WTO (World Trade Organization) framework.

Development of strategies

National, subregional and regional integrated intervention strategies (Figure 1) should be developed to support smallholder farmers' efforts in rice production to ensure domestic food security, income generation and poverty reduction in order to improve the rural lives of farmers. The strategies should address the removal of the major rice production constraints experienced by the smallholder farmers. The strategies should also incorporate research, technology generation and dissemination support to farmers, appropriate government policies and the provision of rural infrastructures.

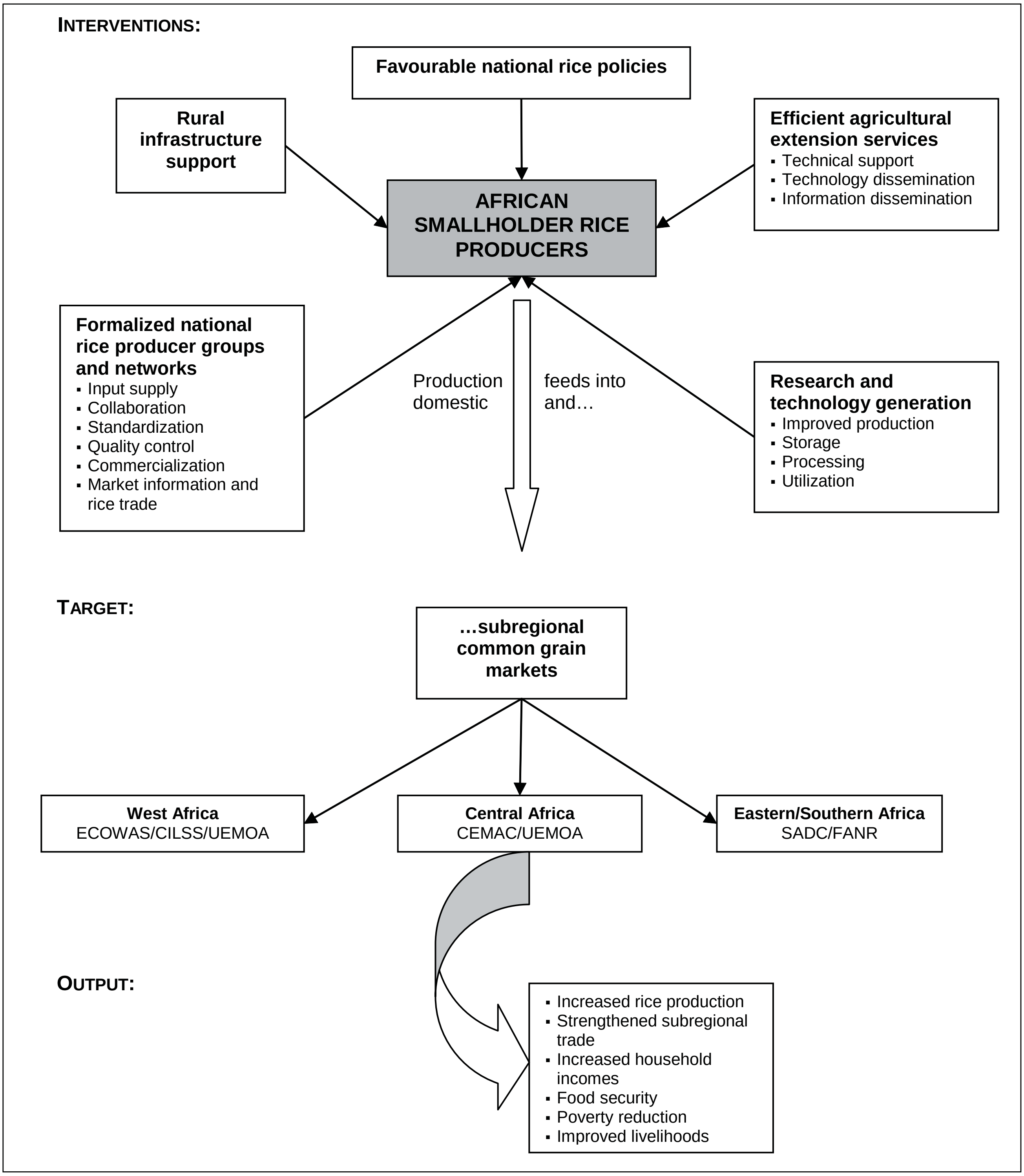
CONCLUSION

Rice forms the basis of the diet of millions of people in SSA. Starch from broken rice is used as laundry starch and has wide industrial applications. By-products, such as rice bran, rice hulls and rice straw, also have several uses.

Rice plays a very important part in efforts to achieve food security and socio-economic development. Rice production contributes to employment and income-generating opportunities for the poor, and thus helps reduce poverty.

Because of the increasing demand for rice and the potential of this crop to improve the rural lives of farming communities, regional strategies should be developed for well-coordinated integrated interventions to promote increased and sustainable rice production in smallholder farming systems. The application of scientific research for generation and effective dissemination of appropriate rice production technologies should be an important component of this strategy. Other components of this strategy include: adoption of national rice policies, coordinated access to credit, restoration of farm input subsidies, improvement of crop production and post-harvest technologies, strengthening of national

FIGURE 1
Integrated intervention strategy for promoting increased and sustainable smallholder rice production and trade in Africa



Note: Prepared by Kebe and Youdeowei (based on the analysis of the rice situation in the document and the strategy proposed for the removal of constraints).

agricultural extension services, formation/strengthening of rice farmers' associations, restoration of guaranteed rice prices, research support, aggressive marketing of locally produced rice, and collaboration among rice stakeholders.

Furthermore, FAO's successful work – in rice IPPM/FFS in West Africa, conservation agriculture, PROD (integrated production systems) and PAIA (priority areas for inter-disciplinary action) – should be expanded and applied to promote increased rice production in African smallholder farming systems.

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Petits exploitations en Afrique: production rizicole et amélioration durable des conditions de vie

La demande de riz, comme aliment de base, a considérablement augmenté dans de nombreux pays d'Afrique subsaharienne ces dernières années surtout dans les pays où le riz n'est pas traditionnellement l'une des principales cultures vivrières. Le riz est à la base de l'alimentation de millions de personnes en Afrique et il représente la principale source d'emplois et de revenus dans de nombreuses régions pauvres et en situation d'insécurité alimentaire du globe, y compris l'Afrique subsaharienne.

Malgré une augmentation sensible des surfaces consacrées aux cultures rizicoles en Afrique (plus 2,61 millions d'hectares de 1997 à 2003), le rendement moyen des céréales (1,87 tonne/ha) reste nettement inférieur à la moyenne mondiale (3,84 tonnes/ha). On a aussi relevé une croissance de la production de riz en Afrique (19,08 millions tonnes de paddy en 2003). La hausse de la consommation de riz en Afrique a conduit à alourdir la facture des importations (1,35 milliards de dollars en 2000) avec une incidence négative sur la balance des paiements des pays africains.

Il a été suggéré d'adopter des mécanismes pour favoriser la production de riz (y compris la transformation ou la commercialisation). Il s'agit notamment du renforcement de l'accès aux crédits et aux intrants, du rétablissement des subventions pour les intrants agricoles, et de l'amélioration de la production et des technologies utilisées après la récolte. On peut aussi citer d'autres mécanismes déterminants comme l'amélioration des services de vulgarisation, la formation et le renforcement des associations de producteurs de riz, le soutien à la recherche, une commercialisation plus agressive du riz produit localement et la collaboration entre les parties prenantes dans le secteur du riz.

La recherche sur le riz a permis d'élaborer des variétés nouvelles de riz pour l'Afrique (NERICA) susceptibles de contribuer à stabiliser ou à accroître la productivité dans les zones de culture pluviale. Les gouvernements et les partenaires de l'aide au développement devraient soutenir les agriculteurs et leur permettre d'avoir accès à ces variétés. On a également mis au point des technologies améliorées y compris les pratiques de gestion intégrée des cultures rizicoles (comme la gestion intégrée de la production et de la protection contre les ravageurs et les écoles pratiques d'agriculture de la FAO), le RiceCheck australien et les pratiques de gestion intégrée des cultures rizicoles de l'Association pour le développement de la riziculture en Afrique de l'Ouest (ADRAO). Il est nécessaire de former les agents de vulgarisation et de leur donner le matériel nécessaire pour transmettre ces technologies aux agriculteurs qui doivent ensuite apprendre à utiliser ces technologies susceptibles de réduire l'écart de rendement. La collaboration en matière de recherche sur le riz entre les SNRA (Systèmes nationaux de recherche agricole) et le secteur privé devrait être renforcée afin d'accroître la production et améliorer la qualité. En Afrique, les organisations économiques régionales et sous-régionales devraient élaborer des politiques pour favoriser la commercialisation du riz en dehors des frontières nationales. Ces organisations devraient aussi accorder au riz une place de choix, au plan régional et sous-régional, en créant ou en maintenant les réserves alimentaires stratégiques.

Los pequeños agricultores africanos: la producción del arroz y los medios de vida sostenibles

La demanda de arroz como alimento básico en muchos países del África subsahariana ha aumentado considerablemente en los últimos años, sobre todo en países donde el arroz tiene escasa tradición como cultivo alimentario principal. El arroz ha servido como base de la alimentación de millones de personas en África y constituye una fuente principal de empleo e ingresos en muchas regiones pobres del mundo que padecen inseguridad alimentaria, como por ejemplo el África subsahariana.

En África la superficie de producción de arroz ha aumentado de forma considerable, con un incremento de 2,61 millones de hectáreas entre 1997 y 2003. No obstante, el rendimiento medio de grano para África (1,87 toneladas/ha) es muy inferior al promedio mundial (3,84 toneladas/ha). También la producción del arroz ha aumentado en África, donde se produjeron 19,08 millones de toneladas de arroz en 2003. El aumento del consumo de arroz en este continente ha provocado un incremento de la factura de importaciones, que ascendió a 1 350 millones de dólares EE.UU. en el año 2000, afectando negativamente a la balanza de pagos de los países africanos.

Se han propuesto mecanismos para fomentar la producción de arroz, incluida la elaboración o la comercialización, entre los que figuran la mejora del acceso a créditos e insumos, el restablecimiento de las subvenciones a los insumos agrícolas y la mejora de las tecnologías de producción de cultivos y de post-cosecha. Otros mecanismos importantes son la mejora de los servicios de extensión, la formación/fortalecimiento de las asociaciones de agricultores arroceros, el apoyo a la investigación, la comercialización dinámica del arroz producido localmente y la colaboración entre las partes interesadas del sector del arroz.

Las investigaciones sobre el arroz han producido las variedades NERICA (Nuevo Arroz para África), que consiguen una productividad más elevada y estable en las ecologías de las tierras altas de secano. Los gobiernos y los asociados en el desarrollo deberían prestar asistencia a los agricultores y posibilitarles el acceso a estas variedades. Se han desarrollado también tecnologías mejoradas, entre las que figuran los sistemas de gestión integrada de cultivos del arroz, como por ejemplo la iniciativa de Producción Integrada y Manejo de Plagas/Escuelas de Campo para Agricultores de la FAO, la metodología australiana RiceCheck y el sistema de gestión integrada de cultivos del arroz del ADRAO. Es necesario capacitar a los agentes de extensión y dotarles de lo necesario para que puedan hacer llegar estas tecnologías a los agricultores. Además, los agricultores necesitan recibir capacitación para emplear estas tecnologías de producción y salvar así la brecha de rendimientos. Debería reforzarse la colaboración en la investigación sobre el arroz entre los Sistemas nacionales de investigaciones agronómicas (SNIA) y el sector privado a fin de aumentar la producción y mejorar la calidad. Las organizaciones económicas subregionales y regionales de África tendría que formular políticas que facilitasen la comercialización del arroz a través de las fronteras nacionales, así como otorgar al arroz un lugar central en la creación o realización de las reservas estratégicas de alimentos subregionales y regionales.

Achievements and impact of NERICA on sustainable rice production in sub-Saharan Africa

J. Rodenburg, A. Diagne, S. Oikeh, K. Futakuchi, P.M. Kormawa, M. Semon, I. Akintayo, B. Cissé, M. Sié, L. Narteh, F. Nwilene, S. Diatta, Y. Sere, M.N. Ndjiondjop, O. Youm and S.O. Keya
Africa Rice Center (WARDA), Cotonou, Benin

In terms of production, rice is the fourth most important cereal (after sorghum, maize and millet) in sub-Saharan Africa (SSA). It occupies 10 percent of the total land under cereal production and accounts for 15 percent of total cereal production (FAOSTAT, 2006). Approximately 20 million farmers in SSA grow rice and about 100 million people depend on it for their livelihoods (Nwanze *et al*., 2006). Rice is the staple food of a growing number of people in SSA: from 1961 to 2003 consumption increased at a rate of 4.4 percent per year (Kormawa, Keya and Touré, 2004). Among the major cereals cultivated, rice is the most rapidly growing food source in Africa: between 1985 and 2003, the annual increase in rice production was 4 percent, while production growth for maize and sorghum was only about 2.4 and 2.5 percent, respectively (Kormawa, Keya and Touré, 2004).

The most widely grown rice species, *Oryza sativa*, is originally from Asia and was introduced into Africa only about 450 years ago. Another less well-known rice species, *O. glaberrima* (Steud), is originally from Africa and was domesticated in the Niger River Delta over 3 500 years ago (Viguier, 1939; Carpenter, 1978). As a result of their evolution, domestication and breeding history, both species have distinct and complementary advantages and disadvantages for use in African farming systems. The Asian rice (*O. sativa*) is characterized by good yields, absence of lodging and grain shattering, and high fertilizer returns – unlike its African counterpart (*O. glaberrima*). However, in contrast to Asian rice types, landraces of *O. glaberrima* often have good weed competitiveness and resilience against major African biotic and abiotic stresses (Koffi, 1980; Jones *et al*., 1997a).

Dalton and Guei (2003) concluded that research into genetic enhancement of rice generated approximately US$360 million in 1998, compared with a total investment of just US$5.6 million. This is evidence that rice variety improvement has a potentially enormous impact on the economic development of SSA. Numerous conventional breeding efforts have been made to improve the performance of upland rice (*O. sativa*) for use in African farming systems. These efforts have had only limited success, partly because the Asian rice, *O. sativa*, lacks resistance or tolerance to many of the typical African stresses (Jones *et al*., 1997a).

In 1992, the Africa Rice Center (WARDA) and its partners started the Interspecific Hybridization Project (IHP) in an attempt to combine the useful traits of both cultivated rice species (*O. sativa* and *O. glaberrima*). Crossing the two species is complicated by their incompatibility, which leads to hybrid mortality (hindering heterogenic recombination [Jena and Khush, 1990]) and progeny (F_1) sterility (Second, 1984). This problem was overcome through backcrossings with the *O. sativa* parent coupled with anther culture, resulting in the first interspecific rice progenies from cultivated varieties (Jones *et al*., 1997a, b; Jones, Semon and Aluko, 1997).

With the support of donors from Japan and the United States and in collaboration with numerous partners in the IHP, WARDA developed interspecific lines with desirable traits tailored to African conditions. In 1999, the interspecific lines were named New Rice for Africa: NERICA (WARDA, 1999) and one year later, WARDA received the prestigious CGIAR (Consultative Group on International Agricultural Research) King Baudouin Award for its achievements with NERICAs (WARDA, 2000). This award was followed by: the World Food Prize, awarded to Dr Monty Jones in 2004 in recognition of his leading role in the development of upland NERICA lines; and the Fukui International Koshihikari Rice Prize of Japan, awarded to Dr Moussa Sié in 2006 for his work on lowland interspecifics. NERICA is considered one of the major advances in recent decades in the field of rice varietal improvement (Nguyen and Ferrero, 2006).

NERICA constitutes a wide range of interspecific varieties with different characteristics. NERICA varieties are high-yielding, early-maturing (75-100 days), weed competitive, resistant and tolerant to Africa's major pests and diseases, and tolerant to drought and iron toxicity. These characteristics are clearly not all found in one single NERICA variety. Some of the findings about NERICA varieties are summarized herein; figures are presented on the adoption of NERICA varieties by farmers in SSA and an explanation is provided for how this rapid dissemination took place. The objective is to provide an overview of achievements and to prioritize future research and development (R&D) of NERICA.

IMPACT AND ACHIEVEMENTS

Breeding upland NERICA

Based on their excellent performance and popularity among farmers, 11 new NERICA varieties were named by WARDA´s Variety Nomination Committee in March 2005. This brings the total number of upland NERICA varieties characterized and named by WARDA to 18, including the original seven NERICA varieties (NERICA 1-7) that were named in 2000 (Table 1). All 18 NERICA varieties are suitable for the upland rice ecology of SSA. They were derived from three series of crossings between three different *O. sativa* cultivars and a single *O. glaberrima* accession.

Breeding lowland NERICA

In addition to the upland NERICA varieties, WARDA and national programmes in West African countries developed NERICA varieties suitable for irrigated and rainfed lowlands (Table 2). The unique R&D partnership model forged between WARDA and the national programmes in West African countries through the Regional Rice Research and Development Network for West and Central Africa (ROCARIZ) was central to this success; it facilitated the shuttle-breeding approach to accelerate the selection process and achieve wide adaptability of the lowland NERICAs. Sixty lowland NERICA varieties, with yield potential of 6 to 7 tonnes/ha and good resistance to major lowland stresses, have already received the stamp of approval from farmers in several African countries through the participatory varietal selection (PVS) process. Four lowland NERICA varieties were officially released in Burkina Faso and two in Mali in 2005 (WARDA, 2005a).

Yielding ability

A total of 186 upland NERICAs (WAB450 series) developed from crosses of WAB56-104 (*O. sativa*, *japonica*, an upland improved variety) and CG14 (*O. glaberrima*) were tested with their parents and Bouaké 189 (*O. sativa*, *indica*, a popular high-yielding improved lowland variety in Côte d'Ivoire). They were cultivated in the upland and lowland parts of the continuum in the WARDA experimental fields in M'bé, Côte d'Ivoire in a

TABLE 1
The 18 upland NERICA varieties with their pedigree

Variety	Pedigree	Backcross
NERICA 1	WAB 450-I-B-P-38-HB	WAB 56-104/CG14//WAB56-104
NERICA 2	WAB 450-11-1-P31-1-HB	WAB 56-104/CG14//WAB56-104
NERICA 3	WAB 450-I-B-P-28-HB	WAB 56-104/CG14//WAB56-104
NERICA 4	WAB 450-I-B-P-91-HB	WAB 56-104/CG14//WAB56-104
NERICA 5	WAB 450-11-1-1-P31-HB	WAB 56-104/CG14//WAB56-104
NERICA 6	WAB 450-I-B-P-160-HB	WAB 56-104/CG14//WAB56-104
NERICA 7	WAB 450-I-B-P-20-HB	WAB 56-104/CG14//WAB56-104
NERICA 8	WAB 450-1-BL1-136-HB	WAB 56-104/CG14//WAB56-104
NERICA 9	WAB 450-B-136-HB	WAB 56-104/CG14//WAB56-104
NERICA 10	WAB 450-11-1-1-P41-HB	WAB 56-104/CG14//WAB56-104
NERICA 11	WAB 450-16-2-BL2-DV1	WAB 56-104/CG14//WAB56-104
NERICA 12	WAB 880-1-38-20-17-P1-HB	WAB 56-50/CG14//WAB56-50
NERICA13	WAB 880-1-38-20-28-P1-HB	WAB 56-50/CG14//WAB56-50
NERICA 14	WAB 880-1-32-1-2-P1-HB	WAB 56-50/CG14//WAB56-50
NERICA 15	WAB 881-10-37-18-3-P1-HB	CG14/WAB 181-18//WAB181-18
NERICA 16	WAB 881-10-37-18-9-P1-HB	CG14/WAB 181-18//WAB181-18
NERICA 17	WAB 881-10-37-18-13-P1-HB	CG14/WAB 181-18//WAB181-18
NERICA 18	WAB 881-10-37-18-12-P3-HB	CG14/WAB 181-18//WAB181-18

Note: WAB 56-50, WAB 56-104 and WAB 181-18 are *O. sativa* japonica varieties whereas CG14 is an *O. glaberrima* variety.

TABLE 2

The 60 lowland NERICA varieties with their pedigree

Variety	Pedigree	Backcross
NERICA-L-1	WAS 122-IDSA 10-WAS 1-1-FKR 1	TOG5681/3*IR64
NERICA-L-2	WAS 122-IDSA 10-WAS 6-1-FKR 1	TOG5681/3*IR64
NERICA-L-3	WAS 122-IDSA 11-WAS 11-4-FKR 1	TOG5681/3*IR64
NERICA-L-4	WAS 122-IDSA 11-WAS 8-2	TOG5681/3*IR64
NERICA-L-5	WAS 122-IDSA 12-WAS B-FKR 1	TOG5681/3*IR64
NERICA-L-6	WAS 122-IDSA 13-WAS 10-FKR 1	TOG5681/3*IR64
NERICA-L-7	WAS 122-IDSA 13-WAS 13-3-3 FKR 1	TOG5681/3*IR64
NERICA-L-8	WAS 122-IDSA 14-WAS B-FKR 1	TOG5681/3*IR64
NERICA-L-9	WAS 122-IDSA-10-WAS-3-1-TGR 3	TOG5681/3*IR64
NERICA-L-10	WAS 122-IDSA-10-WAS-7-2-FKR 1-TGR 89	TOG5681/3*IR64
NERICA-L-11	WAS 122-IDSA-11-WAS-10-2-TGR 60	TOG5681/3*IR64
NERICA-L-12	WAS 122-IDSA-11-WAS-B-IER-11-19	TOG5681/3*IR64
NERICA-L-13	WAS 122-IDSA-13-WAS 10-WAB-B-TGR 5	TOG5681/3*IR64
NERICA-L-14	WAS 122-IDSA-1-WAS 2-WAB 1-TGR 6	TOG5681/3*IR64
NERICA-L-15	WAS 122-IDSA-1-WAS-2	TOG5681/3*IR64
NERICA-L-16	WAS 122-IDSA-1-WAS-2-B-1-TGR 132	TOG5681/3*IR64
NERICA-L-17	WAS 122-IDSA-1-WAS-2-WAB 2-TGR 7	TOG5681/3*IR64
NERICA-L-18	WAS 122-IDSA-1-WAS-4-B-1-TGR 121	TOG5681/3*IR64
NERICA-L-19	WAS 122-IDSA-1-WAS-6-1	TOG5681/3*IR64
NERICA-L-20	WAS 122-IDSA-1-WAS-B	TOG5681/3*IR64
NERICA-L-21	WAS 124-B-3-4-FKR 1	TOG5681/3*IR1529-680-3-2
NERICA-L-22	WAS 126-B-8-1-FKR1-TGR 96	TOG 5681 / 2*IR 64 //IR 31785-58-1-2-3-3
NERICA-L-23	WAS 127-IDSA 2-WAS 3-5-FKR 1	TOG 5681/2*IR 64//IR31851-96-2-3-2-1
NERICA-L-24	WAS 127-IDSA 2-WAS 3-6-FKR 1	TOG 5681/2*IR 64//IR31851-96-2-3-2-1
NERICA-L-25	WAS 127-IDSA-2-WAS-1	TOG 5681/2*IR 64//IR31851-96-2-3-2-1
NERICA-L-26	WAS 161-B-1-1-FKR 1	TOG5681/4*IR64
NERICA-L-27	WAS 161-B-2-B-1	TOG5681/4*IR64
NERICA-L-28	WAS 161-B-2-B-2	TOG5681/4*IR64
NERICA-L-29	WAS 161-B2-B3	TOG5681/4*IR64
NERICA-L-30	WAS 161-B-2-B-4	TOG5681/4*IR64
NERICA-L-31	WAS 161-B-4-1-FKR 1	TOG5681/4*IR64
NERICA-L-32	WAS 161-B-4-B-1-TGR 51	TOG5681/4*IR64
NERICA-L-33	WAS 161-B-4-B-2	TOG5681/4*IR64
NERICA-L-34	WAS 161-B-6-3-FKR 1	TOG5681/4*IR64
NERICA-L-35	WAS 161-B-6-4-FKR 1	TOG5681/4*IR64
NERICA-L-36	WAS 161-B-6-B-1	TOG5681/4*IR64
NERICA-L-37	WAS 161-B-6-B-4	TOG5681/4*IR64
NERICA-L-38	WAS 161-B-6-B-B-1-B	TOG5681/4*IR64
NERICA-L-39	WAS 161-B-6-WAB-B-TGR 16	TOG5681/4*IR64
NERICA-L-40	WAS 161-B-9-1-FKR 1	TOG5681/4*IR64
NERICA-L-41	WAS 161-B-9-3	TOG5681/4*IR64
NERICA-L-42	WAS 161-IDSA-3-WAS-B-IER-2-4	TOG5681/4*IR64
NERICA-L-43	WAS 163-B-5-3	TOG 5674/4*IR 31785
NERICA-L-44	WAS 186-5-3-FKR 1	TOG5681/5*IR64
NERICA-L-45	WAS 186-B-8-B-1	TOG5681/5*IR64
NERICA-L-46	WAS 186-B-8-B-2	TOG5681/5*IR64
NERICA-L-47	WAS 189-4	TOG 5675/4*IR 28
NERICA-L-48	WAS 191-10-3-FKR 1	IR 64/TOG 5681//4*IR 64
NERICA-L-49	WAS 122-IDSA-1-B-IER-18-6	TOG5681/3*IR64
NERICA-L-50	WAS 191-10-4-FKR 1-TGR 123	IR 64/TOG 5681//4*IR 64
NERICA-L-51	WAS 191-10-WAB-B-TGR 23	IR 64/TOG 5681//4*IR 64
NERICA-L-52	WAS 191-1-5-FKR 1	IR 64/TOG 5681//4*IR 64
NERICA-L-53	WAS 191-1-7-TGR 90	TOG5681/4*IR31785
NERICA-L-54	WAS 191-4-10	IR 64/TOG 5681//4*IR 64
NERICA-L-55	WAS 191-8-1-FKR 1	IR 64/TOG 5681//4*IR 64
NERICA-L-56	WAS 191-8-3	IR 64/TOG 5681//4*IR 64
NERICA-L-57	WAS 191-9-B-2	IR 64/TOG 5681//4*IR 64
NERICA-L-58	WAS 191-9-WAB-B-TGR 24	IR 64/TOG 5681//4*IR 64
NERICA-L-59	WAS 192-3-WAB-B-TGR 25	IR 31785//TOG 5674/4*IR31785-58
NERICA-L-60	WAS 191-9-3-FKR-1	IR 64/TOG 5681//4*IR 64

Note: TOG5681 is an *O. glaberrima* variety; IR numbers are *O. sativa* varieties.

TABLE 3
Yield of interspecific upland varieties compared to their parents (*O. sativa*: WAB56-104 and *O. glaberrima*: CG14) and Bouaké 189 in different ecologies

	Yield (*tonnes/ha*)			
	Upland (1997)	Rainfed lowland (1997)	Irrigated lowland (1998[a])	Mean
NERICAs	2.30	4.01	3.62	3.3
WAB56-104	1.50	3.36	3.17	2.7
CG14	2.83	3.66	5.21	3.9
Bouaké 189	2.21	5.56	7.17	5.0
Mean	**2.2**	**4.1**	**4.8**	

[a] 1998 trial was conducted in off-season.
Source: WARDA, Ecophysiology Unit.

randomized block design with two replications in the 1997 season. In the 1998 off-season, 269 NERICAs (WAB450 series) inclusive of the entries used in the 1997 season were raised in irrigated lowland in an augmented block design with eight blocks in experimental fields at WARDA.

Yield levels differed between growing ecologies (Table 3). CG14 and Bouaké 189 did better under irrigated conditions than the other lines. An explanation for lower NERICA performance in irrigated lowlands is that they were bred through backcrossing with their upland *japonica* parent. Hence the NERICA lines exhibit primarily the characteristics of that parent. On average, NERICAs had better growth and yield than WAB56-104 in all ecologies. A few NERICAs matched Bouaké 189 for yield in lowlands. NERICAs seemed to have higher yield potential compared to the *O. sativa* parent in general.

Tolerance and resistance against biotic stresses

Genotypic resistance or tolerance in rice plays an important role in the reduction of yield losses due to stem borers (*Chilo zacconius*, *Sesamia* spp. and *Maliarpha separatella*). Most of the traditional *O. sativa* varieties grown in West Africa are highly susceptible to stem borer attack. WARDA has generated several thousand interspecific lines, increasing the genetic diversity of rice. It is essential to assess the existence and level of resistance or tolerance against stem borers prior to replacement of landraces (traditional *O. sativa* and *O. glaberrima*) by new interspecific varieties. For this purpose, seven NERICA varieties (NERICA 1-7) were evaluated under natural infestation at M'bé and Boundiali, Côte d'Ivoire during the 2001 and 2002 rainy seasons.

From these screening trials, it appeared that stem borer damage (dead hearts and number of larvae per plant) at 84 days after crop emergence was lower in NERICA 4 than in the other NERICAs. However, in comparable trials in Nigeria (2005), NERICA 1 and 5 were rated as the most tolerant, with infestation levels of less than 10 percent. Hence, care must be taken in extrapolating screening results from one site to another.

Resistance of interspecifics against nematodes was reported by Plowright *et al*. (1999) during screening of *O. glaberrima* and *O. sativa* genotypes and interspecific hybrids produced at WARDA for resistance to *Heterodera sacchari*, *Meloidogyne graminicola* and *M. incognita* R2 in field and pot experiments in Côte d'Ivoire. It was reported that all *O. glaberrima* genotypes were resistant to *H. sacchari* (from Côte d'Ivoire and Ghana), *M. graminicola* (from the Philippines) and *M. incognita* R2. Lines of *O. sativa* were all more or less susceptible to both *H. sacchari* and *M. graminicola*. Two of 14 interspecific progenies (WAB450-I-B-P-105-HB and WAB450-I-B-P-160-HB: NERICA 6) proved to be resistant to *H. sacchari* from Côte d'Ivoire. These lines and two others were also less susceptible to *M. graminicola* than the *O. sativa* parent. From progenies screened against *H. sacchari* from Ghana, WAB450-25-1-10 appeared resistant. However, none of the species or progenies were resistant to *Pratylenchus zeae* and there were no significant differences in field population densities of *P. zeae*, *Mesocriconema onoensis* or *Helicotylenchus dihystera*.

In a randomized complete block design, 67 entries (42 interspecific lines, 24 intraspecific and parental lines) were screened for their resistance against rice blast in Sikasso, Mali in 2003. WAB56-50 – well known for its stable resistance in West Africa – was used as a resistant check. This screening trial revealed three distinct groups:

- 50 lines were better or equal to the check for each of the four screening criteria; 34 of them were interspecifics, including NERICAs 2, 6 and 7.

- 8 lines, of which 4 interspecifics, had an acceptable level of resistance.
- 8 lines, including NERICAs 1, 3, 4, 5 and their *glaberrima* parent CG14, presented a low level of resistance for all the epidemiological parameters. They are significantly less resistant than the check.

These results contradicted earlier results obtained from a trial in M'Bé, Côte d'Ivoire, where NERICAs 1, 2, 3 and 5 were rated as resistant and NERICAs 6 and 7 as susceptible (Séré *et al.*, 2004). This indicates the possibility of a genotype × environment interaction for the expression of blast resistance. Another possibility is that resistance against rice blast is vertical, resulting in differences in variety performance between sites with genetic strains. This should be considered in future screening trials and in support of farmer decision-making.

Tolerance to abiotic stresses

Little information is yet available on the tolerance levels of interspecifics to abiotic stresses as compared to their *O. sativa* or *O. glaberrima* parents. However, the few studies that incorporated interspecific rice varieties in their trials indicated that at least some of them perform satisfactorily under stress conditions. For example, De Dorlodot, Lutts and Bertin (2005) found that interspecific WAB450-1-BP24-HB did not show iron toxicity symptoms at 125 mg/litre Fe^{2+}, despite iron concentration of 3 356 mg/kg in the leaves. As the usual critical toxicity concentration in rice is 700 mg/kg, this could be indication of the existence of iron toxicity tolerance among NERICAs.

Preliminary data from WARDA also suggest the existence of valuable genetic material among the interspecific progenies for use in drought-prone environments (Gridley, personal communication). In a screening trial in Ibadan, Nigeria, WARDA scientists were able to identify 88 drought-tolerant lines, of which 58 percent were interspecific lines from crosses with WAB450, -878, -880, -881 and -891. Currently, scientists from WARDA are working on drought tolerance in rice. In collaboration with NARS (National Agricultural Research Systems) scientists from IER (Institut d'Economie Rurale, Mali), they have identified drought-tolerant accessions among floating ecotypes of the *O. glaberrima* species. These accessions constitute the base materials for developing drought-tolerant inter-specific cultivars through backcrossing.

TABLE 4
Time to maturity of four upland NERICA varieties

NERICA variety	Time to maturity (*days*)	(s.e.) [a]
1	101.8	
2	104.8	
3	96.6	
6	101.9	(1.71)

[a] s.e. = standard error.
Source: WARDA, 2006.

Growth duration

An experiment was conducted to evaluate the growth cycle length of four NERICA varieties (NERICAs 1, 2, 3 and 6). They were evaluated in the forest agro-ecology at Ikenne, Nigeria in 2004. NERICA 3 matured much earlier (97 DAS – days after sowing) than the other lines (a difference of 3-5 days), while NERICA 2 had a longer cycle than the rest (>2.5 days) (Table 4). The relative short life cycles observed in this experiment confirmed earlier statements in favour of NERICA. These shorter growth durations could be a useful trait to escape drought, compete with weeds and enable the farmer to diversify the cropping system through intercropping or rotations (Nguyen and Ferrero, 2006).

Phosphorus responses

Several studies have shown that phosphorus is one of the most deficient nutrients in African farming systems and one of the major constraints to upland rice production (Hedley, Kirk and Santos, 1994). Imported chemical fertilizers put a large burden on the livelihoods of small-scale farmers and cheaper alternatives are, therefore, required. For P fertilizer, the solution could be the use of locally produced rock phosphate, which is widely available in Burkina Faso, Mali, Niger, Nigeria, Senegal and Togo. In a long-term field experiment (1998-2001) on an Ultisol of the humid forest zone in Côte d'Ivoire, yield responses of four interspecific upland rice varieties to rock phosphate were compared to the *O. sativa* parent (WAB56-104). Rock phosphate from Mali was applied once in 1998 at a rate of 150 kg/ha (recommended to farmers) and the residual effect was measured in 1999, 2000 and 2001. Adjacent control plots did not receive rock phosphate.

In general, both with and without additional P, the NERICAs gave higher yield than their *O. sativa* parent (level of significance not tested). Only the *O. sativa* parent showed an overall (4-year average) significant effect of P on yield (Table 5). In three of the four years, the *O. sativa* parent showed a positive yield response of 48 to 87 percent with rock phosphate applications. Among the interspecifics, WAB450-11-1-P-40-I-H did not respond significantly to application of rock phosphate throughout the experimental period. Grain yield of WAB450-34-3-2-P-18-HB was significantly increased by 210 percent in 1999 and 143 percent in 2001, while WAB450-1-B-P-38-HB (NERICA 1) responded (145 percent) to rock phosphate applications only in 1999. Results showed a strong year effect on the response of interspecifics to rock phosphate and they indicate that none of them had a consistent response in comparison with the *O. sativa* parent.

Weed competitiveness

A fundamental concept in the development of NERICA was its potential morphological advantage in terms of weed competitiveness. High leaf area index (LAI) and ground cover enable the plant to shade the ground and suppress weeds – traits which could help farmers to reduce the labour and time required for weeding. Confirmation is required that NERICAs possess these weed competitive traits. Furthermore, farmers adopting NERICA need to know what variety to use under weedy conditions.

Five varieties (NERICA 1, 2 and 7, and their parents WAB56-104 and CG14) were tested in a trial in Sikasso, Mali, in 2004. At harvest, CG14 had a significantly higher number of tillers (152/m^2) than the other varieties (98-130/m^2). NERICA 1 was the second best in terms of tiller number per m^2 (130). CG14 and NERICA 7 produced significantly taller plants (80 and 78 cm, respectively) than the other varieties (59-64 cm). Differences in grain yield were not significant (WARDA, 2006).

In experiments carried out in Dassa, Benin, in 2005, three lowland interspecifics (WAB1159-4-10-15-1-2, -2-12-11-6-7 and -6-10) showed high potential in weed competitiveness as a result of their superior leaf expansion at early vegetative growth stages (WARDA, 2006). From experiments in Mali, the most promising lowland interspecifics in terms of weed competitiveness were (1) WAB1159-4-10-15-1-2, (2) WAB1159-2-12-11-5-3, (3)

TABLE 5
Response of four upland NERICAs and their *O. sativa* parent (WAB56-104) to fresh rock phosphate in 1998 and to residual P in 1999, 2000 and 2001[a]

P rate (kg/ha)[b]	Grain yield (*tonnes/ha*)				
	1998	1999	2000	2001	Mean
			WAB56-104		
0	0.75	1.01	0.47	0.85.	0.77
150	1.40[c]	1.57[c]	0.72	1.26[c]	1.24[c]
l.s.d. (0.05)	0.589	0.475	0.431	0.170	0.416
			WAB450-1-B-P-38-HB (NERICA 1)		
0	1.26	0.58	0.51	0.92	0.82
150	2.07	1.42[c]	0.80	1.20	1.37
l.s.d. (0.05)	1.134	0.740	0.430	0.382	0.672
			WAB450-11-1-P-40-HB		
0	1.61	1.16	0.71	0.60	1.02
150	2.20[c]	1.65	0.90	1.11[c]	1.47
l.s.d. (0.05)	0.517	0.652	0.298	0.359	0.456
			WAB450-11-1-P-40-I-H		
0	1.71	0.99	0.78	0.71	1.05
150	2.21	1.71	0.93	1.18	1.51
l.s.d. (0.05)	0.920	1.283	0.448	0.638	0.822
			WAB450-34-3-2-P-18-HB		
0	1.07	0.42	0.42	0.38	0.57
150	1.90	1.30[c]	1.02[c]	0.95	1.29
l.s.d. (0.05)	0.875	0.464	0.570	0.652	0.640

[a] Long-term experiment on an Ultisol of the humid forest zone in Côte d’Ivoire.
[b] l.s.d = least significant difference.
[c] Significant (P< 0.05).

Source: WARDA, 2005b.

-2-1, (4) -2-10, (5) -6-7 and (6) -6-10, thus confirming some of the Benin observations (numbers 1, 5 and 6).

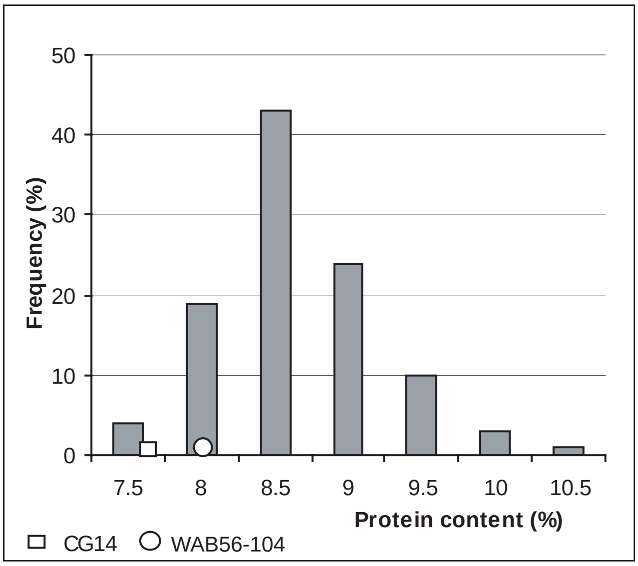
These results show that some of the weed competitiveness characteristics of the *O. glaberrima* parent were actually inherited by some of the NERICA lines, but no combination of competitive traits was found in one single NERICA, confirming earlier studies by Dingkuhn *et al*. (1998, 1999). They showed that interspecific upland rice varieties may combine the weed competitive characteristics of the African parent (*O. glaberrima*) with the yield, resistance to lodging and grain shattering characteristics of the Asian parent (*O. sativa*) (Dingkuhn *et al*., 1998). However, the interspecific progenies do not often equal the weed competitiveness of their *O. glaberrima* parent (Dingkuhn *et al*., 1999).

Grain quality

The protein content of grains of 50 interspecific progenies developed from crosses between WAB56-104 (*O. sativa*) variety and CG14 (*O. glaberrima*) were investigated by Watanabe *et al*. (2006). The materials all came from the same irrigated lowland fields at WARDA's research station in M'bé, Côte d'Ivoire between 1997 and 1999. Total nitrogen content was determined from milled rice samples by near infrared reflectance analyser. Protein content, expressed as a percentage of the total dry weight of the milled rice, was calculated by multiplying the total nitrogen content by a conversion factor of 5.95.

Contrary to the usual high protein content of *O. glaberrima*, in CG14 it was always lower than in WAB56-104. Results show that 72 percent of the interspecific progenies had higher protein content than the average of their parents and 50 percent of them had higher protein content than their *O. sativa* parent WAB56-104 (Table 6). Figure 1 shows the frequency distribution

FIGURE 1
Frequency distribution of protein content



Source: WARDA, 2005a.

of protein content in grains of a population of interspecific (*O. glaberrima* × *O. sativa*) progenies, compared to their parents, CG14 (*O. glaberrima*) and WAB56-104 (*O. sativa*) (WARDA, 2005a). A substantial part of the interspecific progenies have protein content superior to that of their parents.

From another test conducted by the Africa Rice Initiative (ARI), Sasakawa Global 2000 (a non-governmental organization – NGO) and the University of Arkansas (United States), the protein content of non-parboiled grains from NERICA (1-4 and 6) was compared to that of imported rice from Taiwan and China. The protein content of the NERICAs ranged from 8.33 to 13.25 percent (mean: 10.18 percent), while the imported rice contained only 7.58 percent (Taiwan) and 7.94 percent (China).

TABLE 6
Share (%) of interspecifics with minor, intermediate or superior grain protein content compared to their *O. glaberrima* (CG14) and *O. sativa* (WAB56-104) parents

Season	Percentage of interspecific progenies			
	Below the lower parent (CG14)	Between the parents	Above the higher parent (WAB56-104)	Above the average of the parents
1997	19	15	66	75
1998	9	40	51	83
1999 (off-season)	6	62	32	60
Mean	**11**	**39**	**50**	**72**

Source: Watanabe *et al*., 2006.

Technology transfer using WARDA´s partnership model

One of the most important elements in the assessment of success of NERICA is its adoption by farmers. The testing and dissemination of NERICAs in West and Central Africa (WCA) is being done through an innovative process. Farmers make their own selection of useful varieties through participatory variety selection (PVS). The PVS approach adopted by WARDA is part of a 3-year programme:

- Year 1. WARDA scientists and extension agents establish a "rice garden" in a target community, often in the field of a leading or an innovative farmer. The rice garden contains 60-100 different intra- and interspecific rice varieties (both traditional and modern). Farmers are asked to select their favourites.
- Year 2. Farmers grow their selected varieties in their own fields together with their traditional varieties.
- Year 3. Farmers can purchase seed of preferred varieties for their own use.

This approach has been applied in all 17 member states of WARDA. Through PVS, farmers are exposed to new varieties in general and NERICA in particular, and PVS enables breeders to learn from farmers which varieties are appreciated and for what reasons. The PVS approach has played a vital role in the diffusion and adoption of NERICAs, both within and outside the communities directly involved (Diagne, in press).

Since 2000, the ROCARIZ network has supported the development and testing of new lowland rice progenies using breeders from WARDA and from four countries in West Africa: Niger, Mali, Burkina Faso and Togo. In 2004, ROCARIZ encouraged other national programmes in the subregion (WCA) to jointly test 65 new inter- and intraspecific lowland rice progenies, which were hitherto only being tested in the above-mentioned four countries. For this scaling-up activity, the PVS approach was adopted.

The study aimed to identify the farmers' needs and preferences for rice varieties by involving farmers in the identification and selection of varieties. It earlier revealed the different preferences between men and women farmers. Although they sometimes prefer the same varieties, they do so for different reasons. Women prefer high-yielding varieties, to ensure they can feed their family, whereas men give higher value to taste and like varieties that perform well with few inputs (Jones and Wopereis-Pura, 2002). An additional aim was to identify promising inter- and intraspecific progenies for irrigated and lowland ecologies based on the evaluation of agro-morphological characterization of the progenies and on their tolerance to diseases and pests.

Sixty-two interspecific (*O. glaberrima* × *O. sativa indica*) and eight intraspecific fixed lines (*O. sativa indica* × *O. sativa indica*), which had been tested in Burkina Faso, Mali, Senegal and Togo and multiplied in Burkina Faso, were sent through ROCARIZ to eight other countries (the Gambia, Guinea, Sierra Leone, Benin, Nigeria, Cameroon, the Democratic Republic of the Congo and Ghana) during the 2004 wet season. At grain filling, score was kept of plant height, growth cycle and other agronomic and morphological traits. In the final evaluation, emphasis was placed on grain quality (grain size, shape and ease of threshing). At each stage, each farmer was allowed to make a maximum of three to five selections.

In the Gambia, 13 men and 12 women took part in the scoring at maximum tillering stage. All the participating farmers selected three varieties. The most important selection criteria for farmers were grain yield, followed by the height of the plant. They preferred medium to tall plants (>60 and <100 cm) for weed competitiveness, while none of the farmers selected progenies of short stature (Table 7).

Overall, four varieties dominated the choices made by farmers (Table 8).

PVS is followed by a community-based seed system (CBSS) approach that is quicker and more efficient than the conventional seed system. CBSS uses farmers' practices and indigenous knowledge to supply seed to small-scale farmers (Jones and Wopereis-Pura, 2002).

In order to support widespread dissemination of NERICAs, several tonnes of foundation seeds were produced in 2005. This was made possible through the NERICA Dissemination Project funded by the African Development Bank (AfDB), the United Nations Development Programme (UNDP) and the Rockefeller Foundation, with the technical input of experts from the Japanese International Cooperation Agency (JICA). The African Rice Initiative (ARI), responsible for NERICA seed dissemination, produced more than 16 000 tonnes of foundation seed at WARDA (Table 9) and assisted in foundation seed production in different pilot countries (Table 10).

NERICA lines have been tested in 31 SSA countries. Sixteen different NERICA lines have been released and adopted in 15 countries, the number of varieties per country ranging from one to seven (Table 11). In 2005, NERICA varieties were produced on more than 100 000 ha in SSA:

- >10 000 ha: Guinea, Côte d'Ivoire and Uganda
- 5 000-10 000 ha: Mali, Togo, Nigeria, the Congo, the Democratic Republic of the Congo and Kenya
- <5 000 ha: a total of 14 countries

TABLE 7
Farmers´ ranking of traits at rice maturity, the Gambia, 2004

Trait	Frequency	% of people selecting
High-yielding	20	80
Height	15	60
Panicles (per m^2)	14	56
Panicle exertion	12	48
Erect flag leaf	12	48
Filled grains (%)	10	40
Grain size	8	32
Panicle size	5	20
Grain shattering	5	20
Leaf colour	3	12

Source: WARDA, 2006.

TABLE 8
Varieties most preferred by a cross-section of Gambian farmers, 2004

Variety name	Total frequency	Selection (%)
ITA 212	8	32
WAS122-IDSA-1-WAS-2-B-1-TGR 132	7	28
WAS49-B-B-9-1-4-TGR 48	4	16
WAS 124-B-3-4- FKR 1	4	16
WAS 161-B-9-3	3	12
WAS 161-B-9-1-FKR 1	3	12
WAS 191-4-10	3	12

Source: WARDA, 2006.

In order to increase the adoption rate of NERICA, ARI facilitated the introduction of more than 400 NERICA lines to farmers through PVS.

Socio-economic impact

Rice makes an important contribution to world food security. An estimated 840 million people currently suffer from hunger; over 50 percent live in areas where rice is vital for food, income and employment (Nguyen and Ferrero, 2006). On the basis of these figures, improved yields and returns through the use of NERICA should logically result in enhanced food security and improved livelihoods in Africa. Scientists at WARDA and national partners have done several impact assessment studies on NERICA. The impact assessment methodology followed at WARDA is based on the "counterfactual" outcomes or average treatment estimation (ATE) framework underlying modern evaluation theory and practice (Diagne, 2006a).

In all countries, work is being conducted exclusively by the NARS economists participating in the ROCARIZ network. WARDA provides funds (through the ROCARIZ funding mechanism), training and tools for analysis and backstopping on the fieldwork and data analyses. The only exception is the work in Côte d'Ivoire, for which WARDA is fully responsible. A common methodology is being used in all countries in order to facilitate the comparison and aggregation of its adoption and impact. Table 12 summarizes some of the impact assessment studies carried out in Côte d'Ivoire, Guinea and Benin (Adegbola, Arouna and Diagne, 2006a, b, c; Diagne, 2006b; Diagne *et al*., 2006).

Results from this study showed that the adoption rate in Côte d'Ivoire could have been 28 percent in 2000 instead of the actually observed 4 percent, had the whole

TABLE 9
Production and distribution of NERICA seed by ARI Coordination Unit

Year	Seed produced (*kg*)			Seed distributed (*kg*)			No. beneficiary countries to date
	BS [a]	FS [b]	Total	BS [a]	FS [b]	Total	
2003	75	350	425	65	350	415	2
2004	151	1 063	1 214	100	1 000	1 100	4
2005-06	1 474	14 102	15 576	1 400	13 900	15 300	17 [c]
Total	**1 700**	**15 515**	**17 215**	**1 565**	**15 250**	**16 815**	

[a] BS: breeder seed.
[b] FS: foundation seed.
[c] Benin, Burkina Faso, Democratic Republic of the Congo, Ethiopia, the Gambia, Ghana, Guinea, Kenya, Mali, Mozambique, Nigeria, Sierra Leone, Tanzania, Togo, Uganda, India and the Philippines.
Source: WARDA, 2006.

population been exposed to NERICAs, and assuming that access to seed was not a constraint. The potential adoption of NERICA, realized by a successful NERICA dissemination project, is therefore thought to be large (Diagne, 2006a). Adegbola, Arouna and Diagne (2006a, c) showed the importance of availability of information on improved varieties. In their study site in Benin, 1 995 ha were cultivated with NERICAs in 2004; it is estimated that this could have been 5 486 ha if farmers had been well informed about these varieties.

Cultivation of NERICA varieties has also had a positive effect on the school rate of children (Adékambi, Diagne and Biaou, 2006). This positive effect is partly the result of NERICAs' shorter growth cycle and higher weed competitiveness (alleviating the labour burden put on children) and partly a result of the higher yields and quality which generate higher revenue.

TABLE 10

Production of seeds in pilot countries, 2005

Country	Quantity (*tonnes*)	Seed category [a]
Benin	15	FS
Gambia	986	CS and FS
Ghana	36	FS
Guinea	806	CS and FS
Mali	50	FS
Nigeria	250	FS
Sierra Leone	260	CS and FS
Total	**2 603**	

[a] FS: foundation seed; CS: certified seed.

Source: WARDA, 2006.

Publications and awards

In terms of public and scientific awareness, NERICA has undergone considerable development since it was given its official name in 1999. Numerous local newspapers and policy-makers have cited NERICA all over the world. Work related to interspecifics between *O. sativa* and *O. glaberrima* has been published in approximately 47 scientific papers to date and cited in numerous other scientific and public media (Table 13). Particularly worthy

TABLE 11

Upland NERICA varieties released and adopted (×) in selected countries

	NERICA																
	1	2	3	4	5	6	7	8	10	11	12	13	14	15	17	18	Total
Benin	×	×															2
Burkina Faso											×	×		×	×	×	5
Congo									×								1
Congo (DRC)				×		×	×										3
Côte d'Ivoire	×	×	×	×	×												5
Ethiopia	×			×		×											3
Gambia	×	×	×	×	×	×	×										7
Ghana	×																1
Guinea	×	×	×	×	×	×	×										7
Kenya										×							1
Mali				×				×					×				3
Nigeria	×	×	×														3
Sierra Leone	×	×	×	×	×	×											6
Togo	×		×	×													3
Uganda				×													1
Total	**9**	**6**	**6**	**9**	**4**	**5**	**3**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**51**

Source: WARDA, 2006.

TABLE 12

NERICA adoption in Côte d'Ivoire (2000), Guinea (2001-03) and Benin (2003-04)

	Côte d'Ivoire	Guinea	Benin
Diffusion rate (%)	9	54	26
Adoption rate (%)	4	21	18
Adoption rate (%) after exposure [a]	-	57	68
Estimated potential adoption rate (%) [b]	27	-	50
Area (*ha*) under NERICA	-	51 000 [c]	1 995
Potential area (*ha*) under NERICA	-	150 000	5 486

[a] Adoption rate of a random sample of farmers of the population.

[b] Potentials are the estimations about the whole population, based on the assumption that all farmers had been exposed to NERICA and seed would be available.

[c] 16% of the total area under rice production in Guinea.

of note are the great number of valuable contributions by Dr Monty Jones and Dr Michael Dingkuhn, including their important breakthrough article (together with Dr Aluko and Dr Semon) in *Euphytica*, 1997 (cited 25 times in peer-reviewed scientific articles). Moreover, the aforementioned awards for achievements in interspecific hybridization, and the interest from numerous donors are proof of the international and scientific appreciation of NERICA.

TABLE 13
Publications [a] on NERICA or interspecific hybrids

Year			
1996-98	1999-2001	2002-04	2005 - present
17	11	10	9

[a] Articles in peer-reviewed journals, conference proceedings, book chapters, published reports and monographs.
Sources: WARDA, CAB abstract, Current Contents and Scopus.

CONSTRAINTS, RESEARCH GAPS AND OUTLOOK

One of the biggest constraints to the successful use of NERICAs is the availability of seed. NERICA can only have a greater impact on livelihoods of farmers in SSA if the seed supply system is enhanced. A study conducted by WARDA revealed that only 29 percent of the farmers interviewed were cultivating improved high-yielding rice varieties (Kormawa, Keya and Touré, 2005). The reason for this was a severe lack of availability of seed. An estimated 250 000 tonnes of NERICA seed would currently be needed to replace all upland rice production in Africa (Kormawa, Keya and Touré, 2005). A major constraint observed is that in most African countries, the national agricultural extension and other systems are not sufficiently developed and have not been responsive to farmers' needs for new technologies. Another constraint noted was the relative high cost of complementary inputs (fertilizers, pesticides, water) compared to low rice prices. Kormawa, Keya and Touré (2005) concluded that, despite the wide dissemination of NERICA in Africa, there is an urgent need for the development of a strong market and a prominent position for it on national policy agendas. To achieve significant and sustainable increments in rice production, a comprehensive rice sector development programme will be required in the major rice-producing countries, as part of the overall agricultural development plan. Among the most important prerequisites for capturing the full benefits of agricultural technologies such as NERICA are political and social stability (Nwanze *et al.*, 2006), requiring the removal of unfair subsidies, active involvement of the private sector, improved availability of farmers to credits and inputs, and an overall improved infrastructure (Nwanze *et al.*, 2006) – factors that are not easily met in sub-Saharan Africa.

WARDA needs to continue with the characterization of NERICA varieties in order to support farmers in their decision-making. This should be done for each ecology and at different input levels. Results from these studies should be published both in peer-reviewed scientific journals and in the form of fact sheets or extension manuals, in order to reach the scientific community as well as the farmers. In terms of breeding, considerable progress can be made through the use of more advanced biotechnological methods. The obviously rich gene pool of *O. glaberrima* should be explored in a more systematic and rapid way than through the usual crossings. The availability of a molecular linkage map and molecular markers could help in the introgression of desirable traits and the exclusion of undesirable ones, such as sterility (Sarla and Mallikarjuna Swamy, 2005).

CONCLUSION

It can be concluded that some of the interspecific rice varieties have a yield advantage over their *O. glaberrima* and *O. sativa* parents – as a result of the absence of grain shattering; the presence of superior weed competitiveness, drought tolerance, and pest or disease resistance; or higher yielding potential. In addition, the grain quality of most of the interspecifics is often better than that of their parents. Combined with higher yields, this can significantly contribute to food security and improved nutrition in SSA.

NERICA can also have a significant positive impact on the economy of rice-producing and -consuming countries in Africa. If these improved varieties can be combined with improved post-harvest technologies, both quantity and quality of local rice could be significantly enhanced. This would make local rice more competitive with imported rice from Asia. Policy-makers in Africa could also play an important role in the promotion of locally produced and processed rice, through implementation of a suitable system of subsidies and taxes. In terms of R&D concerning NERICAs, the priorities of WARDA and its partners are:

- Characterize released NERICA varieties to support farmer decision-making.
- Continue the search for appropriate NERICA varieties with superior yields, and resistance, tolerance or competitiveness against the major African production constraints, such as drought, salinity, iron toxicity, stem borers, rice blast, termites and (parasitic and non-parasitic) weeds.
- Develop integrated rice production systems to enhance the capacities of NERICA varieties.
- Develop and disseminate appropriate post-harvest technologies that help in safeguarding the quality of NERICA rice and enhance farmers' income.
- Continue the assessment of impact of NERICA on improved livelihoods of the poor.
- Increase the exposure of farmers to NERICA.
- Strengthen the national research and development systems as well as the private sector to maximize the production and dissemination of NERICA seed.

The most important conclusion is that NERICA is a success. While no single NERICA variety combines all the useful characteristics and NERICA is no "miracle" variety, the level of diffusion and adoption of these varieties is unprecedented. Farmers highly appreciate NERICA, a fact which alone justifies the promotion and broad dissemination of this technology.

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Résultats obtenus et répercussions du riz NERICA dans la production rizicole durable en Afrique subsaharienne

En Afrique subsaharienne, le riz est l'un des aliments de base d'une population en rapide expansion. L'espèce la plus couramment cultivée est *Oryza sativa*, originaire d'Asie. Elle permet d'obtenir des rendements élevés et répond bien aux intrants, mais elle n'est pas bien adaptée aux conditions africaines. L'autre espèce de riz cultivée à des fins alimentaires – *Oryza glaberrima* – est originaire d'Afrique. Les spécialistes de l'Association pour le développement de la riziculture en Afrique de l'Ouest (ADRAO) et ses partenaires nationaux ont réussi à effectuer un croissement entre deux espèces de riz, et à obtenir une descendance viable dans de nombreuses variétés qui associent les avantages des deux espèces. Ces variétés interspécifiques, dénommées NERICA (Nouveau riz pour l'Afrique) ont été rapidement adoptées par les agriculteurs. À l'heure actuelle environ 100 000 hectares sont consacrés à la culture du riz NERICA en Afrique.

Le nombre de variétés de riz NERICA disponible à ce jour s'élève à 18 pour le riz pluvial et à 60 pour le riz irrigué. Les rendements du riz NERICA sont pratiquement équivalents ou légèrement supérieurs à ceux des parents, en fonction du niveau des intrants et du milieu. Les riz NERICA pluvial ont un période de croissance brève (environ 100 jours). Les variétés de riz NERICA sont résistantes aux ravageurs africains et aux maladies; elles sont aussi tolérantes vis-à-vis du stress abiotique. Les variétés de riz NERICA sont parmi les variétés de riz le plus souvent choisies par les agriculteurs et le taux potentiel d'adoption est de 68 pour cent. Pour l'instant une forte pénétration de cette technologie en Afrique subsaharienne est entravée principalement par le manque de semences.

Les variétés de riz NERICA ont besoin d'une caractérisation détaillée pour permettre aux agriculteurs de prendre des décisions. En outre des technologies complémentaires devraient être élaborées ou commercialisées afin d'améliorer les résultats et la qualité. Pour que des technologies comme le riz NERICA puissent renforcer la sécurité alimentaire dans la région, il faut au préalable assurer le développement d'un secteur privé de production des semences**,** favoriser un meilleur accès des agriculteurs aux semences et à l'information et prévoir des politiques qui soutiennent le développement du secteur agricole.

Logros y repercusiones de la variedad NERICA en la producción sostenible del arroz en el África subsahariana

El arroz constituye uno de los alimentos básicos de la cada vez mayor población del África subsahariana. La especie de arroz cultivada de forma más generalizada, *Oryza sativa*, se introdujo desde Asia. Posee un rendimiento alto y buena respuesta a los insumos, pero no se adapta bien a las condiciones africanas. La otra especie cultivada para consumo humano, *Oryza glaberrima*, es originaria de África. Científicos del Centro Africano del Arroz (ADRAO) y sus asociados nacionales obtuvieron resultados satisfactorios al cruzar ambas especies de arroz, que dieron lugar a descendientes viables y, finalmente, a una amplia gama de variedades que combinan algunas de las ventajas de ambas especies. Estas variedades interespecíficas se denominaron Nuevo Arroz para África (NERICA) y fueron adoptadas rápidamente por los agricultores. Hoy en día, hay unas 100 000 hectáreas de producción de NERICA en África.

El número de variedades NERICA distribuidas hasta la fecha es de 18 para las ecologías de las tierras altas y 60 para las de las tierras bajas. Los rendimientos de estas variedades son en general iguales o ligeramente superiores a los de los progenitores, dependiendo del nivel de insumos y de la ecología. Las variedades NERICA para las tierras altas tienen un período de crecimiento breve, de unos 100 días. Se ha descubierto que estas variedades tienen resistencia a algunas de las principales plagas y enfermedades africanas, así como tolerancia a condiciones adversas abióticas. Las variedades NERICA suelen encontrarse entre las preferidas principalmente por los agricultores y su tasa potencial de adopción es del 68 %. En la actualidad, la disponibilidad de semillas constituye la limitación más importante para esta tecnología alcanzando gran repercusión en el África subsahariana.

Es necesario disponer de una caracterización detallada de las variedades NERICA para ayudar a los agricultores en la toma de decisiones. Además, deberían desarrollarse o distribuirse tecnologías complementarias que mejorasen el rendimiento y la calidad. Algunos requisitos previos para que tecnologías como NERICA aumenten la seguridad alimentaria en la región son el desarrollo de un sector privado de semillas, la mejora del acceso a las semillas y a la información por parte de los agricultores, y las políticas de apoyo al desarrollo del sector agrícola.

Regional strategies for sustainable rice-based production systems in Asia and the Pacific: challenges and opportunities

G. Keerthisinghe

Senior Plant Production Officer, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand

The need to identify promising agricultural practices to enhance food security, sustain rural livelihoods and preserve natural resources is becoming increasingly important for most developing countries, mainly due to the rapidly growing population and limited availability of productive land. The world population is expected to reach 8 billion by the year 2025 and almost all of this increase will be in developing countries (Cakmak, 2002).

In this context, rice plays a major role, as it is the staple food for over half the world population and provides employment for over 1 billion people, who either work directly in rice production or in related support activities (Tran, 2004). In Asia and the Pacific, rice is grown in 26 of the 46 member countries, occupying one-fifth of the region's arable and permanent crop land. The region produces and consumes more than 90 percent of the world's rice. The rice farming system gives part-time employment to some 300 million men, women and children.

The Asia and the Pacific region produced an average of 532 million tonnes of paddy in the triennium 2001-03, but production needs to increase to about 700 million tonnes by 2025 in order to feed the increasing population. In the last 40 years, production grew faster than the population (2.4 percent versus 1.9 percent per annum), giving a per caput gain of 0.5 percent. However, production growth rates are slowing steadily over the decades: from 2.9 percent per annum in the 1960s to 1.3 percent in the 1990s. About 80 percent of the production gains were due to yield increases rather than area expansion. Regional yield improvement averaged 2.0 percent per annum over 40 years to reach a triennial average of 4.0 tonnes/ha in 2001/03. Yield gains were also faster in the earlier decades, decelerating from 1.9 and 2.3 percent per annum in the 1960s and 1970s, respectively, to 1.5 and 1.0 percent in the subsequent decades (FAO, 2004a).

The two main challenges faced by rice in Asia are:

- enabling nations to meet their national and household food security needs with a declining natural resource base; and
- breaking the vicious cycle of poverty and environmental degradation in a large part of the sector.

Land degradation, especially in the fragile rainfed or upland environments, is posing a serious threat to sustainable rice production. Most rice lands can be considered degraded in one way or another. Downstream silting, nutrient mining, pesticide pollution, soil acidification, alkalization, toxicity and salinization and other phenomena continue unabated in irrigated as well as rainfed rice ecosystems. The population in Asia is expected to increase from the current 3.7 billion to 4.6 billion in 2025, resulting in intensification of land use in both favourable and marginal lands (Cantrell and Hettle, 2004). According to Beinroth, Eswaran and Reich (2001), even with a high level of inputs, most Asian countries will not be able feed their populations without irreversibly degrading their land resources.

Competition for scarce water resources is another major constraint to increasing agricultural production in developing countries. Agriculture is by far the largest user of water, accounting for around 70 percent of water withdrawals worldwide and 90 percent in low-income developing countries (Meinzen-Dick and Rosegrant, 2001). Moreover, rapidly growing municipal and industrial water demand in developing countries will increase water scarcity for agriculture, and with a continued slowdown in water investments, it could be a serious threat to future growth in food production (Rosegrant and Ximing, 2001). This is especially true for rice, as rice requires about two times as much water as other grain crops and it is the dominant irrigated crop, occupying over 30 percent of the total irrigated area. By 2025, it is expected that 2 million ha of irrigated dry-season rice and 13 million ha of irrigated wet-season rice will experience physical water scarcity (Tuong and Bouman, 2002). One of the main challenges will be to identify efficient water-use technologies for rice production, such as intermittent flooding and growing rice under aerobic conditions. In rice-wheat cropping systems, the sowing of wheat after rice harvest under zero tillage practices seems to be a promising approach for saving water. Moving away from anaerobic to aerobic rice will have an impact on other processes, such as soil organic matter turnover, nutrient dynamics, carbon sequestration, soil productivity, weed ecology and greenhouse gas emissions, and therefore it is essential to consider all these parameters in identifying integrated management practices to save water (Cantrell and Hettle, 2004).

The size of rice holdings is decreasing in the region, as a result of subdivision for inheritance, sale, leasing and state redistribution. For example, in Nepal, the average rice holding size fell from 0.83 to 0.65 ha between 1971 and 1991, and in India average all-farm size fell from 2.3 to 1.6 ha in the same period. To the extent that they are worked more intensively and distributed more equitably, smaller rice farms are acceptable. In terms of livelihood, however, there is a minimum holding size below which the income generated cannot provide an adequate level of living.

ROLE OF IYR 2004 IN ADDRESSING THE MAJOR CONSTRAINTS TO SUSTAINABLE RICE PRODUCTION

Improving and sustaining the rice-based cropping systems while preserving the environment holds considerable challenges and opportunities. The main aim of the International Year of Rice 2004 (IYR 2004) was to address these issues in a global, coordinated framework, in order to positively harness the potential of properly managed rice-based systems for enhancing food security and sustaining the natural resource base. To address these issues, the International Rice Research Institute (IRRI) requested and obtained FAO's support to have an International Year declared for rice. This was pursued by FAO member countries, resulting in the declaration at the 57th Session of the United Nations General Assembly (UNGA) of 2004 as the International Year of Rice with the theme *Rice is Life*. The UNGA invited FAO to facilitate the implementation in collaboration with other relevant organizations: the United Nations Development Programme (UNDP); the Consultative Group on International Agricultural Research centres (CGIAR); national, regional and international agencies; non-governmental organizations; and the private sector.

IYR provided an opportunity for the global community to focus and work together to increase and sustain the productivity of rice-based cropping systems, which will benefit over a billion households in Asia, Africa and America, who depend on rice systems for their main source of nourishment, employment and income. Furthermore, IYR focused on achieving the internationally agreed goals set out in various global initiatives (1992 Rio Summit and elaborated in Agenda 21's chapter on Sustainable Agriculture and Rural Development [SARD]; United Nations Millennium Declaration in 2000) with the main aim of alleviating poverty and hunger.

The IYR strategy was to employ the year as a catalyst for information exchange and the initiation of medium and long-term programmes for sustainable rice development. For this reason, the establishment of IYR committees at national and regional level was an essential aspect of the year and FAO placed particular emphasis on supporting the formulation of national programmes and development strategies for the medium and long-term. To achieve its objectives, observance of IYR was expected to result in a number of outputs at all levels to increase understanding, provide development guidance and act as a catalyst for longer-term action. Outputs at global, regional, national and community level were identified and discussed in detail in the IYR Concept Paper (FAO, 2003).

Role of rice in improving nutrition and food security

More than 2 billion people still suffer from micronutrient malnutrition. Although rice provides a substantial amount of dietary energy, it has an incomplete amino acid profile and contains limited amounts of essential micronutrients. Since rice is a crop rich in genetic diversity and with wide variation in mineral and protein content, it would be of interest to investigate the nutritional properties inherent in diverse rice varieties to identify varieties with higher nutritional value that could contribute to reducing the global burden of malnutrition. Moreover, fortification techniques can be used to add essential vitamins and minerals to the grain. Unfortunately, this practice is not widespread in many rice-consuming countries, due to limited infrastructure for processing, regulatory control and marketing of fortified foods.

Diversification

Diversification of rice-based cropping systems to incorporate legume crops, modify crop rotations and link with livestock or fisheries is one of the promising approaches to enhance household food security, both through improving producer income and adding essential fatty acids, vitamins and minerals to the diet. Research has highlighted the potential of using legumes as intercrops, catch crops or green fodder crops for enhancing soil fertility and crop yields in the rice-wheat systems which occupy 24 million ha in the Asian subtropics.

Biotechnology

The possibilities of harnessing newly emerging concepts and techniques in cellular and molecular biology need to be explored for better understanding and development of new varieties with enhanced nutritive value, such as “Golden Rice” with high vitamin A content. However, in order to move forward with appropriate and safe use of novel technologies, governments, producers and consumers should be informed of the potential benefits, risks and limitations of new technologies. In this context, more support is needed to develop the infrastructure to support and regulate these advances, including adequate systems for the transfer of appropriate technology and methods of monitoring changes in food security.

Water management

Rice-based production systems will continue to undergo change in coming years as a consequence of scarce water resources. It is important to raise awareness of the importance of identifying techniques for efficient use of water in rice-based systems and to promote the transfer of promising technologies to the end-users. At present, many approaches are being tested for rationalizing water scarcity within rice-based systems, such as the development of rice varieties suited to dry soils (aerobic rice), water-saving irrigation techniques, zero or low tillage practices in rice-wheat systems, and recycling of water for aquaculture or irrigation. The impact of these technologies on water and nutrient management, soil organic matter, carbon sequestration and the emission of greenhouse gases needs to be further investigated.

Environment-friendly agricultural practices

For sustenance of rice-based cropping systems, it is important to identify cost-effective production systems with minimum impact on the environment. This involves a range of agricultural practices, such as the use of rice varieties adapted to local environments, efficient use of nutrients and water, use of appropriate diagnostic tools for need-based nutrient management, integrated management of pests, weeds and diseases, inclusion of legumes, recycling of crop residues, and judicious management of all nutrient sources available for maintenance of soil fertility. One of the main challenges is to identify appropriate management practices best suited for a particular agro-ecosystem, considering the availability of inputs and the socio-economic conditions. It is important to facilitate this process through exchange of information and transfer of best-suited technologies to the end-users. This includes innovative means of sharing and exchanging knowledge among research institutions and providing services to growers without large public service support. Successful examples, such as farmer field schools, exist and can be more widely promoted.

Post-harvest production activities

In spite of the progress made in the prevention of post-harvest losses in rice, in developing countries on average about 15 percent of losses occur due to post-harvest operations, such as drying, milling and storage. The major reasons for these losses are poverty, insufficient or scarce access to technical information, and lack of access to appropriate technologies. Moreover, the importance of “adding value” to rice products, a term that refers to processing activities that strategically use all parts of the harvest for economic return (to produce high-value rice pellets to feed fish from low-value broken rice) needs to be emphasized. Most rice-growing countries require assistance to support the activities related to servicing and maintenance of tools, implements and equipment needed for post-harvest operations.

It is important for rice-producing and rice-consuming countries to work in close collaboration to promote joint research and development activities to boost productivity, income and sustainability gains.

ALLEVIATING POVERTY IN RICE-BASED LIVELIHOOD SYSTEMS

Many rice growers face bleak prospects in terms of employment, income generation and sustainability of resource endowments. What is needed is restructuring of the rice sector through quick and comprehensive re-allocation of resources for future cost-effective production on a sustainable basis. However, owing to cost and welfare considerations, developing countries are trying to adopt a middle path, i.e. maximizing production for near-term poverty alleviation, while simultaneously laying the foundations to restructure the sector (FAO, 2004b). Considering the importance of this subject, alleviating poverty in rice-based livelihood systems has been identified as one of the main thematic programme areas of the FAO Regional Office for Asia and the Pacific. The overall objective is to alleviate poverty and enhance incomes of farm households whose livelihoods are traditionally based on rice production. The specific objectives are as follows:

- Attain and maintain comparative advantages of diversified livelihood systems.
- Realize relatively high incomes from productive, resilient and diversified farming systems, non- and off-farm employment, and industrial and service activities.
- Arrest and reverse natural resource degradation and environment pollution.

In line with the above objectives, FAO is actively involved in supporting the member states (Myanmar, Philippines, Thailand, Indonesia etc.) in the identification of promising technologies for integrated management of natural resources and inputs for sustainable development of rice-based production systems. For example, in Southeast Asia, FAO has sponsored three technical cooperation projects – in Thailand, the Philippines and Indonesia – to introduce and popularize the Australia-derived procedures of farmer-group-oriented RiceCheck/IRCM (integrated rice crop management). These projects will enable rice smallholders to raise rice yields and optimize gross margins and hence increase net income from rice production and thereby strengthen the competitiveness of rice farming. They aim to help rice smallholders adopt novel self-learning, income-enhancing procedures that complement integrated rice crop management, and to provide supportive capacity-building and training to national- and devolved-agency agricultural-development/extension personnel.

In addressing the issues and responding to the needs of member states for the development of cost-efficient rice-based production systems, one of the main challenges is to identify appropriate management practices best suited for a particular agro-ecosystem, considering the availability of the inputs and socio-economic conditions. Some of the major issues that need to be addressed are as follows:

- Identification of cost-effective and sustainable production systems (e.g. legumes in rice-wheat; integrated crop-livestock-fish farming systems).
- Adoption of environment-friendly agronomic practices to increase productivity and conserve the natural resource base (e.g. integrated plant nutrient management systems; integrated pest management; conservation of farming practices).
- Use of crops with superior resource-use efficiency and adaptation to harsh environments.
- Availability of nutrient inputs based on: more site-specific information; nutrient supply and crop demand; multinutrient interactions; and nutrient requirements for the whole cropping system rather than for individual crops.
- Adoption of labour-saving cultural practices (mechanization processes).
- Reinforcement of the system of land-use planning, land tenure and land administration (best practices of agro-ecological zoning).
- Farm management capacity-building (e.g. farm agribusiness linkages; livelihood diversification).
- Planning of policies to redress land degradation, water scarcity, and air and water pollution.
- Establishment of rural non-governmental micro-finance institutions.
- Provision of technical assistance in the key areas of rice commodity and trade analysis, market information, market liberalization and privatization.
- Generation of on-farm, off-farm and non-farm employment to arrest urban migration (e.g. value-adding post-harvest operations; agribusiness and agro-industry).

The complexity, diversity and utility of the rice-based ecosystems underscore the need for a coordinated, international approach to sustainable rice development.

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Stratégies régionales pour les systèmes rizicoles durables en Asie et dans le Pacifique: enjeux et perspectives

La culture du riz est implantée dans 26 des 46 États Membres de l’Asie et du Pacifique et plus d’un cinquième des terres arables et des cultures permanentes sont affectées à cette culture. En tant qu’aliment de base il fournit la principale source de calories de la région. Les systèmes de subsistance basés sur le riz jouent un rôle essentiel dans la région et fournissent un emploi à temps partiel à quelque 300 millions d’hommes, de femmes et d’enfants.

La dégradation des terres, surtout dans les zones pluviales fragiles est une grave menace pour la production durable de riz. On estime que la plupart des rizières sont touchées d’une manière ou d’une autre. La productivité et la durabilité des rizières sont menacées, non seulement par la dégradation des ressources naturelles mais aussi par les changements climatiques à l’échelle du globe.

La diminution de la superficie des exploitations constitue un autre problème important: les rizières locales sont de plus en plus petites du fait des subdivisions pour héritage, de la vente et de la location et des redistributions publiques des terres. Les petites exploitations permettent une culture plus intensive et une répartition plus équitable. Cela dit, au-dessous de certaines dimensions, les agriculteurs ne peuvent plus obtenir les revenus nécessaires à assurer un niveau de vie suffisant.

Pour une meilleure sensibilisation à l’importance du riz dans la région, le thème « Réduire la pauvreté des communautés pratiquant essentiellement la riziculture » a été retenu dans l’un des principaux programmes destiné à orienter le travail de la FAO dans la région jusqu’en 2015. La FAO participe activement au soutien d’un certain nombre de projets – en particulier en Indonésie, au Myanmar, aux Philippines et en Thaïlande – l’accent étant mis sur la gestion intégrée des ressources naturelles et des intrants pour le développement des systèmes de subsistance basés sur le riz pour l’agriculture durable et le développement rural. Le plus difficile consiste à déterminer les pratiques de gestion le mieux adaptées à un écosystème agricole donné, en tenant compte de la disponibilité des intrants et des conditions socio-économiques.

Estrategias regionales relativas a los sistemas de producción sostenible basada en el arroz en Asia y el Pacífico: desafíos y oportunidades

El arroz se cultiva en 26 de los 46 Estados Miembros de la región de Asia y el Pacífico y se siembra en más de la quinta parte del total de tierras arables y de monocultivo. Como alimento básico, constituye la fuente más importante de calorías en la región, donde los medios de vida basados en el arroz desempeñan un papel dominante al ofrecer empleo a tiempo parcial a unos 300 millones de hombres, mujeres y niños.

La degradación de tierras, sobre todo en los frágiles entornos de secano o de tierras altas, plantea una grave amenaza para la producción sostenible del arroz. La mayor parte de las tierras de cultivo de arroz pueden considerarse en modo alguno deterioradas. La productividad y sostenibilidad de estas tierras se ve amenazada no sólo por la degradación de la base de recursos naturales, sino también por el cambio climático mundial.

Otro problema relevante es la disminución del tamaño de las explotaciones agrícolas. Las explotaciones de arroz en la región se vuelven más pequeñas a consecuencia de las subdivisiones realizadas con motivo de herencias, ventas, arrendamientos y redistribución estatal. Las pequeñas explotaciones agrícolas se trabajan de forma más intensiva y se distribuyen más equitativamente, pero desde la perspectiva de los medios de vida, existe un tamaño mínimo para las explotaciones por debajo del cual los ingresos generados no pueden ofrecer un nivel de vida apropiado.

Para conseguir sensibilizar a la región de la importancia del arroz, se determinó que “La mitigación de la pobreza en sistemas de subsistencia basados en el arroz” fuera una de las esferas temáticas principales del programa para orientar la labor de la FAO en la región hasta el año 2015. La FAO participa activamente apoyando una serie de proyectos en la región, sobre todo en Indonesia, Myanmar, Filipinas y Tailandia, que se centran en la gestión integrada de los recursos naturales e insumos para desarrollar sistemas de subsistencia basados en el arroz destinados a lograr una agricultura sostenible y el desarrollo rural. Identificar las prácticas de gestión adecuadas que mejor se ajusten a un determinado agroecosistema, teniendo en cuenta la disponibilidad de insumos y las condiciones socioeconómicas, sería uno de los retos principales.