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ORGANISATION DES NATIONS UNIES POUR L'ALIMENTATION ET L'AGRICULTURE
ORGANIZACIÓN DE LAS NACIONES UNIDAS PARA LA AGRICULTURA Y LA ALIMENTACIÓN
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The *International Rice Commission* (IRC), which works within the framework of FAO, was established on 4 January 1949 with the object of promoting national and international action in respect of production, conservation, distribution and consumption of rice. Matters relating to trade are outside the purview of the Commission.
Membership of the Commission is open to all FAO Member Nations and Associate Members who accept the constitution of the IRC. The present membership of the Commission is 61 and represents all the rice-growing regions of the world.
The Commission keeps under review the scientific, technical and economic problems relating to rice, encourages and coordinates research, organizes (where necessary) cooperative projects and reports to the member countries and the Director-General of FAO on appropriate action to be taken in furthering its objectives.

La *Commission internationale du riz* (CIR), qui opère dans le cadre de la FAO, a été créée le 4 janvier 1949 afin de promouvoir des actions nationales et internationales en matière de production, de conservation, de distribution et de consommation du riz. Les questions de commerce ne sont pas de son ressort.
La Commission est ouverte à tous les États Membres et Membres associés de la FAO qui acceptent son acte constitutif. Elle compte actuellement 61 membres représentant toutes les régions rizicoles du monde.
La Commission traite des problèmes scientifiques, techniques et économiques relatifs au riz. Elle encourage et coordonne les recherches, organise le cas échéant des projets coopératifs et fait rapport aux États Membres ainsi qu'au Directeur général de la FAO sur les mesures à prendre pour réaliser ses objectifs.

La *Comisión Internacional del Arroz* (CIA) se creó, dentro del marco de la FAO, el 4 de enero de 1949. Su objeto es promover la actividad nacional e internacional en el campo de la producción, la conservación, la distribución y el consumo de arroz. Las cuestiones de comercio quedan fuera de su ámbito de acción.
Pueden ser miembros de ella todos los Estados Miembros y Miembros Asociados de la FAO que acepten la constitución de la Comisión. En la actualidad cuenta 61 miembros, que representan todas las regiones arroceras del mundo.
La Comisión sigue de cerca todos los problemas científicos, técnicos y económicos relativos al arroz, fomenta y coordina las investigaciones, organiza en caso necesario proyectos cooperativos, e informa a los Estados Miembros y al Director General de la FAO sobre las medidas que son necesarias para facilitar el logro de sus objetivos.

Articles are in English with summaries in French and Spanish.
Les articles sont en anglais avec des résumés en français et espagnol.
Los artículos son en inglés con resúmenes en francés y español.

INTEGRATED SYSTEMS
SYSTÈMES INTÉGRÉS
SISTEMAS INTEGRADOS

Preface

The collection, analysis and dissemination of information on rice and rice-based production systems is a major activity of the Secretariat of the International Rice Commission in its mission to promote national and international action in matters relating to the production, conservation, distribution and consumption of rice. In this regard and under the guidance of the FAO Steering Committee of the International Rice Commission, the Secretariat publishes an annual volume of the IRC Newsletter.

The International Rice Commission has 61 member countries, and English, French and Spanish are the official languages of the Commission. Until 2002, the volumes of the IRC Newsletter were published in all three official languages. From 2003 to 2005, however, the Newsletter was published in English only, in order to save the available resources for the preparation and subsequent implementation of the International Year of Rice – 2004, declared by the United Nations General Assembly (UNGA). The successful implementation of the International Year of Rice came to a conclusion in December 2005. The implementation of IYR in 2004 was reported to the Second Committee on Poverty Eradication during the 60th Session of UNGA in November 2005. In its Resolution, the Second Committee on Poverty Eradication of UNGA noted:

> *the important contribution that the observance of the International Year of Rice, 2004, has made in drawing world attention to the role that rice can play in providing food security and eradicating poverty in the attainment of the internationally agreed development goals, including the Millennium Development Goals.*

The 21st Session of the International Rice Commission was held from 3 to 5 May 2006 in Chiclayo, Peru with the main theme of “Rice is Life – Bringing the Implementation of IYR to Farmers’ Fields”. This IRC Newsletter Volume 55 contains mainly the keynotes and papers presented during the Session in order to share the current knowledge, thoughts and visions for sustainable rice production systems.

I am pleased to announce that the FAO Steering Committee has decided to resume publication of the IRC Newsletter in all three official languages of the Commission, beginning with the present IRC Newsletter Volume 55, in order to strengthen the dissemination of information to better serve the Commission’s member countries.

Shivaji Pandey
Chairperson, FAO Steering Committee of the
International Rice Commission

Improved rice production in a changing environment: from concept to practice

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The rice subsector has experienced three striking events since the last meeting of the International Rice Commission (IRC), held in 2002 in Bangkok, Thailand. First, the United Nations General Assembly adopted Resolution 57/162, declaring 2004 the International Year of Rice (IYR); it was the first time the UN had dedicated this honour to a single commodity. Second, in 2002 world rice production began to increase once again, following three consecutive years of declining production: world production in 2005 stood at around 614 million tonnes of paddy rice (FAOSTAT, 2005). Third, world average yield in 2005 is projected to break the 4 tonnes/ha barrier. An average yield of 4 tonnes/ha may not appear to be a major accomplishment, but considering that rice is grown on over 150 million ha under a wide variety of conditions from irrigated to dryland to floating, an average yield of 4 tonnes/ha is indeed a significant achievement.

There are, however, also negative factors that plague the rice sector. Rice production in sub-Saharan Africa continues to be outpaced by consumption; imported rice now accounts for over 50 percent of sub-Saharan Africa's rice requirement. Rice is rapidly becoming a food staple in the African diet, and low and stagnant rice production accentuates the food security problem confronting much of sub-Saharan Africa. Food shortage in Africa is becoming synonymous with rice deficit. Excessive water usage, environmental degradation due to pesticide and nutrient contamination, methane emission and ammonia volatilization are a few of the adverse affects of rice production requiring urgent attention. Land and water resources for rice production are diminishing and global climate changes may have a major effect on rice production. There are, however, a wide range of technologies available for reducing the adverse consequences of rice production, but the majority have not been extended to the rice grower. Technology adaptation and adoption remain opportunities and challenges.

In consideration of the entire spectrum of events, the 21st Session of the International Rice Commission is being held in a much more positive environment than most recent sessions. Several of the advances in rice production have emerged from recommendations made at recent IRC sessions, in particular the promotion of improved crop management technologies. The 20th Session in Thailand, as well as the 19th Session in Egypt, made important recommendations for improving yield and bridging the yield gap in irrigated rice. The Expert Consultation on Yield Gap and Productivity Decline in Rice Production in September 2000 in Italy also identified that improved crop management and technology transfer are the principal mechanisms for enhanced yield. FAO and its partners took immediate action on the Commission's recommendations and have made major progress in this important area: there is the potential to enhance the productivity and efficiency of farmers' crop management as well as to help meet global food security requirements. This article gives primary attention to these advances and also reviews other developments that may have important effects on the global rice industry in the near future.

THE CHANGING ENVIRONMENT OF RICE PRODUCTION

Global rice production has met consumption demand during recent decades. However, this situation cannot necessarily be maintained without appropriate action in the near future. The global rice production environment is undergoing substantial changes in numerous areas that require adjustments in rice research and development to support sustainable production.

Increasing rice demand and declining resources for rice production

Worldwide, rice provides 27 percent of dietary energy supply and 20 percent of dietary protein. Rice production nearly doubled during the period from 1970 (316 million tonnes) to 2001 (592.8 million tonnes). The world's rice production, after reaching a peak in 1999, declined during the 2000-02 period and has been increasing again since 2002 (Figure 1), closing the gap between consumption and production. However, there are still 852 million people suffering from hunger and malnutrition and, due to the steady population increase, rice demand is projected to increase from 571.9 million tonnes in 2001 to 771.1 million tonnes in 2030 (FAO, 2003a).

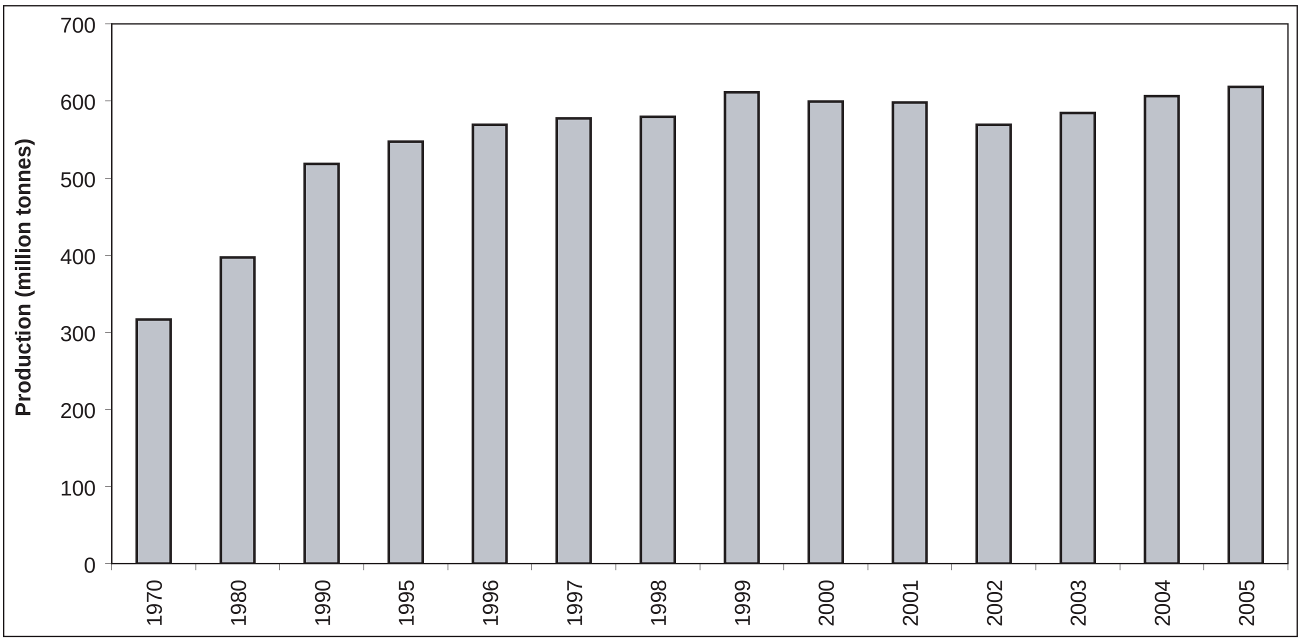
The world rice harvested area grew from 133 million ha in 1970 to 157 million ha in 1999 (FAOSTAT, 2005), mainly as a result of the increase in cropping intensification. In tropical climate areas with favourable temperature regimes, two or more rice crops can be grown on the same land in a year. Rice-rice and rice-other-crop-rice systems are very popular with farmers in Bangladesh, southern China, southern India, Indonesia, Myanmar, the Philippines and Viet Nam. Rice-rice systems are also widely practised in many irrigated lands in sub-Saharan Africa. Continuous rice production systems are common in much of tropical Latin America.

In 2005, the global rice harvested area was 153.5 million ha, i.e. a decline of 3.4 million ha since 1999 (FAOSTAT, 2005). In the near future, the possibility for expanding area under rice-based systems will be limited due to increased competition for land and water from the urban and industrial sectors in the major rice-producing countries in Asia. Outside Asia, inadequate water supply limits rice cultivation in Spain, Portugal, Egypt and Australia (Nguyen and Ferrero, 2005). The Egyptian Government plans to limit the area under rice production due to the limited water supply. In a number of countries in sub-Saharan Africa and Latin America, there is still considerable land area suited to rice production. High development costs are a deterrent to expanding irrigated rice in Africa. Lack of capital and stable economic policies restrict long-term investment in irrigated rice in Latin America, despite the availability of vast land and water resources.

The accumulation of greenhouse gases in the atmosphere is warming the planet, resulting in changes in the global climate (IPCC, 2001). In 1992, Downing reported that the core agricultural zone in Zimbabwe would be reduced by 67 percent with a 2°C temperature increase (Downing, 1992). A later report suggested that agricultural land in low latitude tropical climate regions may be hardest hit by temperature increases (Rosenzweig and Iglesias, 1994). Recently, Darwin *et al*. (2005) estimated that the amount of land classified as “land class 6” – the primary land class for rice, maize, sugar cane and rubber in tropical areas – would decline by 18 to 51 percent in the next century as a result of global warming.

Increasing the productivity of the rice systems has proven an effective means of conserving water and of

FIGURE 1
World rice production



Source: FAOSTAT, 2005.

decreasing greenhouse gases in wetland rice systems by reducing the area under production. The large-scale adoption of hybrid rice (about 50 percent of total rice area) permitted China to increase production from 128 million tonnes in 1975 to 191 million tonnes in 1990, while reducing the rice harvested area from 36 million ha in 1975 to 33 million ha in 1990 (Nguyen, 2004). Increase in productivity has translated into a substantial reduction in the total amount of water consumed in rice production. The practice of intermittent irrigation is also expanding as a potential alternative to the relatively high rate of water consumption in fully flooded irrigated rice.

Changing policy, trade and market agreements

Historically, rice trade has accounted for only a small amount of world rice production; until recently, it was considered relatively unimportant. Rice is generally thought of as the "most protected" crop, since governments have historically intervened in pricing, input supplies, procurement and trade. However, trade in rice has grown into a major international business with the global rice trade amounting to over 26 million tonnes (milled) in 2004, and growth is projected to continue (Calpe, 2005).

Rice protection policies in both developing and developed countries are becoming contested issues in world trade negotiations. The trade liberalization policies resulting from the Uruguay Round of the GATT (General Agreement on Tariffs and Trade) conference in the late 1990s are often considered to be the driving force behind the rapid increase in rice trade. Likewise, failure to reach an agreement at the World Trade Organization (WTO) Cancun meeting was precipitated by agriculture, and rice trade was a major issue.

The questions of market access and export subsidies remain to be resolved. Domestic price support is difficult to negotiate due to the historical importance of rice as a food and a source of income in many major rice-producing countries. Although the international rice trade is still relatively small and accounts for only 7 percent of world production, trade has been shown to assist in reducing large fluctuations in national rice prices and has had a calming effect on world prices.

National rice policies are in a continuous state of evolution, and more changes are anticipated as world production and consumption equalize and other sectors of the economy become increasingly important in the major rice-producing countries. Consequently, rice is no longer viewed as just a subsistence crop in the world market but increasingly as a tradable commodity. Recent studies reported that complete trade liberalization would increase rice trade by between 7 and 73 percent (depending on grain type), increase export prices by 2 to 91 percent, but decrease consumer prices by 18 to 27 percent. Total economic gain from complete liberalization would amount to US$7.4 billion annually with over two-thirds of the gains going to importing countries or rice consumers (Wailes, 2004). This illustrates the potential economic gains and losses involved in rice trade agreements. Although it has not been quantified, similar reductions in government subsidies in the United States and Europe would have major impacts on world trade and rice prices.

Diminishing labour supply and increased concern for environmental conservation

Rice cultivation in many countries is labour-intensive. Labour shortages are being experienced in many rice-producing areas, especially those near urban centres, as farmers migrate to seek more lucrative employment in other sectors of the economy. The labour supply for rice production is diminishing in a number of Asian countries (Pingali, Hossain and Garpacio, 1997). Farm mechanization will be required to sustain rice production as migration from rural to urban areas increases with industrial development. There is a need to foster sustainable mechanization, which is environmentally friendly, ecologically sound and less resource demanding. Direct seeding is growing in popularity in Asia due to labour shortages for transplanting. It requires rice varieties with thicker stems and which are less susceptible to lodging, as well as better land levelling and preparation to ensure adequate plant establishment.

Environmental considerations play an increasingly important role in rice production. Contamination from pesticides and fertilizers is under close scrutiny; programmes such as integrated pest management and integrated nutrient management offer viable alternatives. Reduced subsidies for fertilizers will require greater efficiency; this in turn will bring about changes in cultural practices. In general, the major rice-producing countries have low N-use efficiency. Technology for higher N-use efficiency is available, but has not been adopted by most rice producers. New paradigms in technology transfer are required to expand the use of proven technologies in pest management, fertilizer usage and water management.

Shifting consumer preference and malnutrition in rice-consuming populations

Nutritional value is normally not considered a qualitative factor. The nutritional contribution of rice was reviewed extensively in the 2002 IRC Session (Kennedy, Burlingame and Nguyen, 2003). Essentially, rice in developing countries is an important source of:

- carbohydrates (27-50 percent of dietary energy supply);
- protein (20-50 percent of dietary protein requirements); and
- fat (3-27 percent of dietary requirements).

The variation in meeting dietary requirements is explained by the wide range of rice consumption. In countries such as China and India, rice supplies approximately 9 to 17 percent of the recommended nutrient intake (RNI) of calcium, foliate and iron and nearly 20 percent of the RNI of zinc. In general, rice contains adequate levels of B vitamins (thiamine, riboflavin and niacin) but contains little vitamin C, D or beta-carotene (vitamin A). The bran contains the highest level of dietary fibre, minerals such as Ca, K, Fe, Zn and P, as well as most of the B vitamins. Consequently, rice processing (milling and polishing) significantly reduces the nutritional quality of rice. Most high-yielding varieties contain less than 1.5 mg iron/100 g, but germplasm has been identified containing twice this quantity (Graham *et al.*, 1999; Juliano, 2003). However, iron nutrition is complex and a major problem is the low bioavailability (often only about 18 percent). In addition, there are numerous inhibitors of iron absorption, including phytic acid, polyphenols, vegetable proteins and calcium, as well as enhancers of absorption, including ascorbic acid, organic acids and animal tissues (meat, fish and poultry).

Extensive research is underway to improve the nutritional quality of rice, using both conventional breeding methods and biotechnology. Variation within the species permits the use of conventional breeding methods to improve nutritional characters, avoiding the difficulties with genetically modified organisms (GMOs) (Graham *et al.*, 1999; Kennedy, Burlingame and Nguyen, 2003). Data in Table 1 show the wide range of protein content in rice varieties around the globe. Senadhira, Gregorio and Graham (1998) also reported large variations in the zinc and iron content of different rice varieties. Attempts to improve beta-carotene content led to the "Golden Rice" phenomenon in the mid-1990s, but difficulties encountered in engineering led to delays in its commercial development. Many of these difficulties may now have been resolved and promising new research points to higher levels of beta-carotene (Beyer *et al.*, 2002). Efforts are also underway to increase iron content via several methods, including genetic modification using the ferritin gene from the common bean (Lucca *et al.*, 2000). Although work is at an advanced stage, a major limitation remains consumer acceptance of GMO rice.

Higher incomes as a result of developments in the manufacturing sector are leading to greater demand for higher quality rice. The price of aromatic rice such as Basmati and Khao Daw Mali is much higher than that of HYVs (high-yielding varieties) and the demand for aromatic, soft and long-grain rice continues to increase with improvements in the income of rice-consuming populations, especially in many European countries (Ferrero and Nguyen, 2004). Currently, high quality rice accounts for 75 percent of the international rice trade (Calpe, 2005). Rice breeders will have to be more stringent on grain quality characteristics to meet the requirements of sophisticated consumers.

TABLE 1
Protein content in grains of rice planted around the globe

Source	Sample number	Range of protein content (%)
Oryza sativa L.	2 674	4-14
• Asia	1 626	4-14
• Australia	24	5-10
• North America	190	4-13
• South America	301	5-13
• Europe	233	5-13
• Africa	300	5-11
Oryza glaberrima Steud	195	9-14

Source: Juliano and Villareal, 1993 (adapted).

Emerging partnerships in research and development

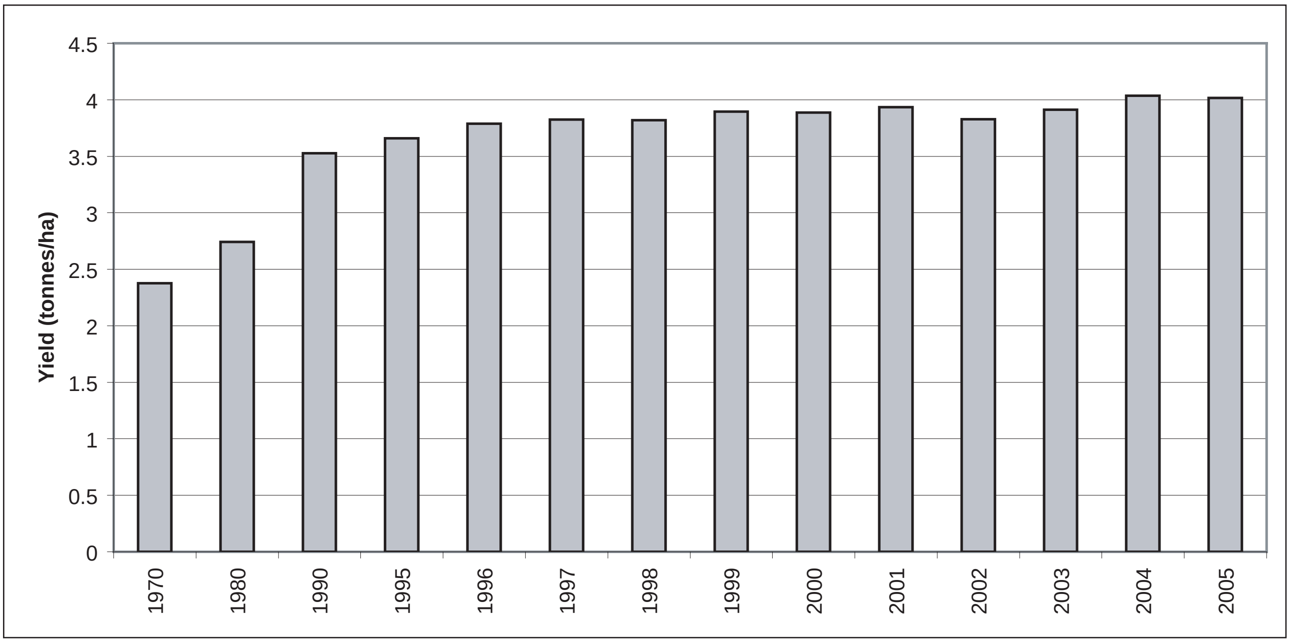
The contribution to rice producers and consumers from research conducted at the international research centres under the CG (Consultative Group [on International Agricultural Research]) system is significant and unquestionable. Both consumer and producer have benefited tremendously from the advances made in research. Further refinements in pest and disease resistance breeding and improved grain quality have added further value to the high-yielding plant types that drove the Green Revolution in the 1960s and 1970s. The worldwide benefits of the Green Revolution were seen in the yield increase of 1.7 tonnes/ha (Figure 2). Although not readily apparent, agronomic research conducted following the Green Revolution is the primary factor fuelling current yield increases.

The CG centres have fostered closer collaborations with national programmes and non-traditional partners, partly as a result of the reduction in resources. The participatory approach to research has helped the centres focus more sharply their research activities. Furthermore, centre-wide initiatives were introduced to reduce duplication of efforts and more cost-effective research programmes. The CG centres have historically been the source of new technologies; current research from these centres and elsewhere will contribute to the continuing effort to further increase rice production that is less resource demanding and less damaging to the environment.

Public sector research and extension programmes have traditionally assumed responsibility for national enhancement of rice production in many countries. In Latin America, however, the demise of the public sector efforts during the 1990s due to structural re-adjustments resulted in the surfacing of a national growers' association as a primary conduit for rice research and development. Currently, the private sector accounts for nearly 80 percent of all expenditures on rice research and development in Latin America. A similar retraction in public sector support to rice has occurred in much of Asia, but the private sector has not often assumed a stronger role in rice development. Little funding is available for laboratory-level or on-farm research activities.

The private sector is an untapped resource for rice development. Private seed companies, fertilizer suppliers, pesticide companies etc. depend on economically successful farmers to be successful themselves. The advancement of technologies that increase farmer profits also produces increased sales of essential inputs. Recently, non-governmental organizations and the private sector have begun to actively invest in rice research, especially in the field of rice biotechnology (Brookes and Barfoot, 2003).

FIGURE 2
World rice yield



Source: FAOSTAT, 2005.

Policy-makers as well as researchers and extension personnel, therefore, need to examine alternative means of support for vital rice research and development. State and district governments are assuming more of a role in several countries, NGOs are operating in all areas of development, input suppliers have a vested interest in the advancement of rice, and millers require paddy to operate. Establishing partnership linkages within the rice chain to pool revenue for research and development is feasible, since all sectors have a vested interest in the success of the crop. Promoting research and development through growers associations is an attractive alternative. For example, FLAR (Latin American Fund for Irrigation Rice) not only derives funds for rice research and development from producers and millers, but it has established agreements with commercial seed and chemical companies. Expanding and widening partnerships among the public sector, NGOs and the private sector will be a central challenge for rice research throughout the world. The FLAR model should be examined by other countries.

FROM CONCEPT TO PRACTICE: CASE STUDIES ON CLOSING THE YIELD GAP IN IRRIGATED RICE PRODUCTION

The 19th Session of the IRC in 1998 directed special attention to the yield gap in irrigated rice and noted that bridging the yield gap was the most appropriate means of increasing yield and profitability in the highly productive irrigated sector. Subsequently, in 2000, FAO organized in Rome an Expert Consultation on Bridging the Yield Gap that provided a forum for analysing the extent of the yield gap in the major rice-producing regions and developing action plans for addressing the problem. These two events, combined with the 20th Session of the IRC, provided the basis for formulating the concept of rice integrated crop management to enhance productivity in irrigated rice, which was then articulated by the Secretariat of the IRC (Nguyen, 2002; Clampett, Nguyen and Tran, 2003). After the 19th Session of the Commission, FLAR, with assistance from the Common Fund for Commodities (CFC), commenced efforts to close the yield gap in several Latin American countries. FAO has assisted Indonesia, the Philippines, Thailand and Viet Nam in initiating activities in integrated crop management and technology transfer. The International Rice Research Institute (IRRI) in collaboration with Indian institutions has also undertaken activities to address the yield gap problem. Finally, a new "compost-based" concept for smallholders emerged from Madagascar and is referred to as the system of rice intensification (SRI). While the activities are being pursued by different organizations, often with distinct methods, they all have the common objective of increasing on-farm yields through the use of improved crop management.

Asian case studies

Improved crop management programmes are also being implemented in several Asian countries, including the Philippines, Indonesia, Viet Nam and India. The programmes are being implemented by several institutions using different technologies and methods of technology transfer. Results from several of the countries are presented in the 2005 issue of the International Rice Commission Newsletter (Vol. 54).

Indonesia

Much research, development and assessment of integrated crop management (ICM) has been carried out by numerous national institutions in Indonesia during the last 5 years (Abdulrachman, Las and Yuliardi, 2005). The programme has evolved from a discipline-oriented on-farm research programme into an active integrated extension programme that utilizes ICM as a methodology with a set of principles for guiding farmers in managing the rice crop with emphasis on the following areas:

- Selection of rice variety for high yield and use of quality seed.
- Planting of young and healthy seedlings.
- Incorporation of organic manure and basal fertilizer prior to transplanting and use of the leaf colour chart for predicting the need for nitrogen top-dressing.
- Use of intermittent irrigation.
- Frequent mechanical weeding.
- Control of pests and diseases based on regular field observations.

The rice ICM system was first evaluated in Grobogan District, Central Java in the wet season (Nov.-Feb.) of the 2000/01 cropping season. In the 2001 dry season, the assessment became part of the National Integrated Crop Management Network of the Indonesian Agency for Agricultural Research and Development (IAARD) and was conducted in seven provinces. In 2002, the Integrated Rice Development Project (P3T) was initiated and developed in 31 districts, located in 14 provinces. The

TABLE 2
Range of yield changes due to application of ICM methodology in 26 villages in Indonesia during three cropping seasons, 2001-02

Range (%) of yield change due to application of ICM	Number of villages
Increase of > 30% to < 50%	6
Increase of > 20% to < 30%	7
Increase of > 10% to < 20%	8
No increase	4
Decrease of > 3%	1
Total number of villages under observation	**26**

assessment of the impact of the application of the rice ICM system during 2001/02 showed that the application of ICM methodology positively increased yield in 25 villages (out of the 26 villages assessed), with yields increasing by more than 20 percent in 13 villages (Table 2). The programme found that new varieties, seed treatment and rodent control were the preferred features of the ICM programme. In contrast, use of the leaf colour chart, organic fertilizer and soil analysis to predict P and K requirements were least accepted by growers.

Philippines

The Philippine Rice Research Institute is implementing a rice integrated crop management system, referred to as PalayCheck (Cruz *et al*., 2005; Olvida, 2005; Publico, 2005). The programme is based upon the application of key checks and is similar to the Australian RiceCheck programme. Technological interventions consist of eight checks, namely:

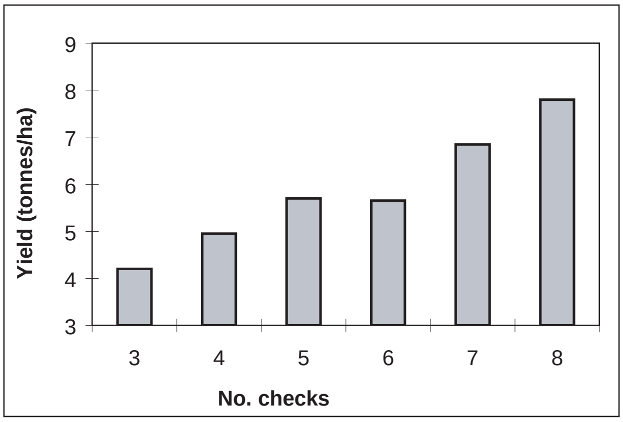
- use of high quality seed;
- land-levelling;
- reduced density and early transplanting;
- use of leaf colour chart for monitoring N nutrition;
- monitoring of panicle size and density;
- water management;
- control of pests, diseases, insects and weeds; and
- harvest at early maturity.

A large number of on-farm demonstration plots show that full compliance with the checks results in yields of over 8 tonnes/ha compared to an average of 4.5 tonnes/ha with conventional crop management (Figure 3). Yield is highly related to adoption of the key checks and ranges from about 4 tonnes/ha from farmers who achieved three key checks to over 8 tonnes/ha from farmers who achieved all key checks. Similarly, gross profit margins nearly doubled from US$421/ha to US$828/ha, due mainly to increased yield. Although some farmers reported high yields, especially during the dry season, the overall impact was limited because the checks were only partially adopted; only 20 percent of the farmer-cooperators followed all eight recommendations. Farmers seldom adopt technologies as “packages”; they normally select component practices that they view as more important. Adoption of several practices (in this case, eight) requires time and much effort. Therefore, during the initial phase of introducing the technologies, it may be necessary to reduce the number of technological interventions resulting in a simpler technical message.

Viet Nam

Viet Nam is employing an integrated crop management programme called “3 Increases, 3 Reductions” (Pham, Trinh and Tran, 2005). The application of this programme follows a participatory approach in which the technology is introduced, tested and subsequently modified based on farmer experience. The programme has not to date resulted in substantial increases in rice yield. Yield increases ranged from 1.7 to 6.3 percent in three cropping seasons in two districts during 2002-04. However, the programme reduced production costs as a result of the decrease in the quantities of fertilizers, pesticides and seed; there were also improvements in grain quality. Rice produced with the “3 Increases, 3 Reductions” programme was cleaner (as a result of the lower incidence of disease infection), resulting in higher whole grain yield from milling. As a result, profits increased from US$44 to US$64/ha/season (Pham, Trinh and Tran, 2005).

FIGURE 3
Yield increase related to use of checks, Philippines



Source: Cruz *et al.*, 2005 (adapted).

India

Collaboration between IRRI and Indian scientists led to the development of an ICM programme incorporating technologies from various sources. The ICM programme is built upon five management factors (Balasubramanian *et al*., 2005):

- early transplanting (4-leaf stage);
- one seedling per hill;
- square transplanting (0.225 × 0.225);
- early and frequent mechanical weeding; and
- intermittent irrigation.

Yield increase on research farms using the five management factors ranged from 35 to 48 percent. Removal of a single component caused the following yield depressions:

- 19 percent due to late weeding;
- 16 percent due to transplanting older seedlings;
- 14 percent due to transplanting more than one seedling per hill; and
- 10 percent due to infrequent irrigation.

On-farm demonstration plots reported yields of 6.6 tonnes/ha with ICM and 4.4 tonnes/ha with conventional management, i.e. a 50 percent yield increase. Profits increased more than threefold from US$105/ha to US$369/ha, due to improvements in crop management. The programme is currently developing procedures for widespread dissemination of ICM technologies.

Latin American case studies

Following the recommendations that emerged from the 19th Session of the IRC in 1998 and the Expert Consultation on Bridging the Yield Gap (FAO, Rome) in 2000, FLAR obtained assistance from the CFC to initiate efforts to bridge the yield gap in several Latin American countries. The following is a summary of the results of this effort in southern Brazil, Venezuela (Bolivarian Republic of), Costa Rica and Nicaragua.

Brazil (Rio Grande do Sul)

Average irrigated rice yield in the state of Rio Grande do Sul in southern Brazil stagnated at 5.2 tonnes/ha in the last 15 years. In 2003/04, FLAR, in collaboration with the state rice growers' association, Rio Grande Rice Institute (IRGA), initiated activities to improve yield through the introduction and promotion of improved crop management (Pulver and Carmona, 2004). The salient features of the technical intervention focus on six strategic management practices:

- Planting date to expose the crop to high solar radiation during the reproductive period.
- Reduced seeding density to produce healthy plants that are less susceptible to lodging with less incidence of foliar diseases.
- Improved pest management based upon insecticide treated seed.
- Balanced nutrition in sufficient quantities for high yield.
- Early weed control.
- Appropriate irrigation water management.

The six practices must be applied in an integrated manner and with precision. Simply adopting one or two of the improved practices and omitting others does not result in the anticipated increase in yield. Likewise, applying the practices at an inopportune time or under inappropriate conditions does not produce the desired results.

In the first year of the project (2003/04), demonstration plots were established on 17 sites. Farmers who applied

TABLE 3

Summary of yields obtained with the most appropriate technology in demonstration plots established on farms with farmer leaders

Region	Yield (*tonnes/ha*)			
	District average	Farmer yield	ICM	Yield increase over district average
Fronteira Oeste Region – 7 sites	5.9	6.7	10.0	4.1
Campanha Region – 2 sites	5.5	5.5	10.0	4.5
Depressão Central Region – 5 sites	5.6	5.8	9.0	3.4
Average of all regions – 14 sites	**5.7**	**6.2**	**9.7**	**4.0**

Source: Pulver and Carmona, 2004 (adapted).

all the practices with precision obtained an average yield of 9.7 tonnes/ha, which is 4 tonnes/ha greater than the regional average and 3.5 tonnes/ha greater than the adjacent commercial fields of the participating farmer (Table 3). From the demonstration plots, established on two sites of commercial size, yields of 12 tonnes/ha were recorded. These are the highest yields that have ever been reported in the state and clearly show that very high yields are feasible even with currently available varieties when accompanied by improved crop management.

In the second year, the programme expanded to cover 52 sites. The mean yield of demonstration plots comprising over 8 000 ha was 9.1 tonnes/ha (2.3 tonnes/ha greater than commercial fields on the same farm) (Table 4). Growers who adopted all the practices but not in the degree required had an average yield of 7.8 tonnes/ha (1.6 tonnes/ha greater than the regional average during the same season). These farmers generally did not reduce the seeding density to the required level. Growers who partially adopted the improved practices obtained a yield of 7.1 tonnes/ha (1.0 tonnes/ha greater than the regional average). Finally, growers who attended only one or two field events and attempted to use the technology but in an imprecise manner reported an average yield of 6.5 tonnes/ha, representing a yield increase of only 0.8 tonnes/ha above the regional average. The varying level of success, depending upon the degree of adoption of the technology, is similar to the yield responses experienced with the adoption of "production checks", popularized by the Australian RiceCheck programme.

In just two growing seasons, the programme incorporated 1 600 farmers over an area of approximately 200 000 ha into the improved crop management programme. The large number of participants and the rapid adoption of the technology are principally due to the extension methodology employed, that is, the "farmer-to-farmer" method. This system is based on farmer-to-farmer exchange, resulting in the autonomous diffusion of technologies. In addition, the use of large-scale demonstration plots provides convincing evidence that the technology being transferred is relevant, easily adjusted to different conditions and simple to adopt.

Venezuela (Bolivarian Republic of)

During the last two decades, the mean rice yield in Venezuela (Bolivarian Republic of) has remained stagnant at 4 to 4.5 tonnes/ha. In the 2003 season, the CFC/FLAR project commenced, providing assistance to the national rice growers' association (FUNDARROZ) with the objective of developing a coordinated technology transfer system (Pulver and Rodriguez, 2004 and 2005). The project collaborates with eight organizations, accounting for approximately 115 700 ha of irrigated rice (nearly 80 percent of the total rice area in the country). During the 2003/04 dry season, demonstration plots with improved management technology gave excellent yields, often exceeding 9 tonnes/ha. The agronomic practices that resulted in improved yields were based on four concepts:

- date of planting that permits the crop to receive maximum solar radiation during the reproductive phases;
- N fertilizer management resulting in high N efficiency;
- early weed control; and
- improved irrigation water management.

In the second year of the project, two additional practices were added:

- use of insecticide-treated seeds to control insect outbreaks during crop establishment; and

TABLE 4

A summary of farmer participation, adoption of improved practices and the resulting impact on yield, production and income for the 2004/05 cropping season

All regions 2004/05 season	No. farmers	Area (*ha*)	Yield (*tonnes/ha*)	Yield increase (*tonnes/ha*)	Production increase (*tonnes*)
Farmer leaders	52	8 467	9.1	2.3	19 124
Farmers with assistance	115	25 805	7.8	1.6	42 291
Farmers without assistance	268	52 107	7.1	1.0	53 154
Indirect participants	1 171	114 209	6.5	0.8	92 247
Total	**1 606**	**200 588**			**206 816**
Value of increased production @ US$150/tonne					US$31 022 400
Increased income/farmer					US$19 317

Source: Pulver and Carmona, 2005 (adapted).

- lower planting density to reduce foliar disease and cost of treated seeds.

National yields in Venezuela (Bolivarian Republic of) are increasing at a faster rate than in any other Latin American country (FAOSTAT, 2005). The current national yield of 5.2 tonnes/ha is approximately 0.5 tonnes/ha greater than the national average prior to the CFC project. Numerous demonstration plots as well as commercial fields have demonstrated that yields of 6 to 7 tonnes/ha are readily feasible during the rainy season and yields of 8 to 10 tonnes/ha are obtainable during the dry season when solar radiation is abundant.

Costa Rica

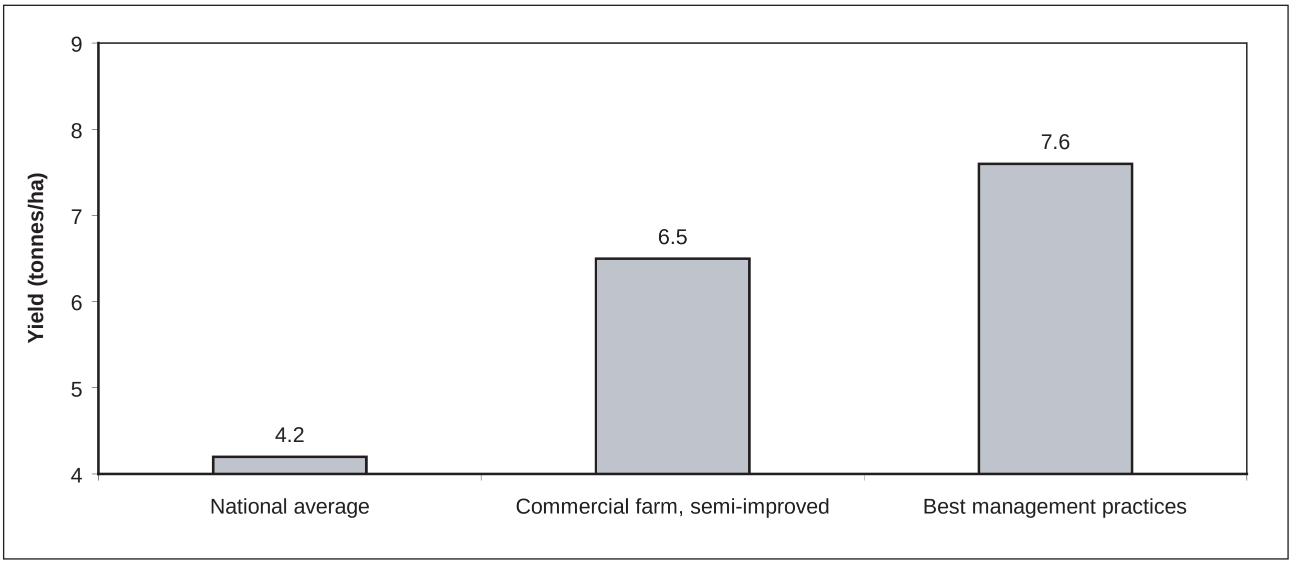
Mean irrigated rice yields in Costa Rica have stagnated at about 4 to 4.5 tonnes/ha over the last 15 years. In the 2003/04 season, demonstration plots were established using the six strategic management practices developed for Venezuela (Bolivarian Republic of), but modified to suit local conditions. On two cooperating farms on a semi-commercial area, yields of 7.5 tonnes/ha (approximately 3.5 tonnes/ha greater than the national average yield under irrigation) were obtained (Oviedas, 2005). In the 2004/05 season, the improved practices were extended to six commercial farms and 1 500 ha were planted using the six strategic practices, resulting in an average yield of 6.5 tonnes/ha (2.3 tonnes/ha greater than the national average). In the same season, demonstration plots planted on the same farms using “best management practices” gave an average yield of 7.6 tonnes/ha over an area of 360 ha (3.4 tonnes/ha greater than the national average) (Figure 4). The “best management practices” are essentially further modifications of the six strategic practices for Costa Rican conditions.

Nicaragua

Yields obtained in the irrigated production system were approximately 4 tonnes/ha during the last decade. The last two seasons saw the FLAR/CFC project, in collaboration with the national rice growers’ association (Asociación Nicaragüense de Arroceros – ANAR), introduce improved crop management practices. The technology consisted of the same six strategic management practices described for Brazil and Venezuela (Bolivarian Republic of), but they were adjusted to the conditions of Nicaragua.

In the 2003/04 season, the technology was introduced on one commercial farm. Yield with improved management was 9.7 tonnes/ha (5.3 tonnes/ha greater than the national average under irrigated conditions). In the second season, the same technology was extended to four commercial farms. The average yield of the “best management practice” farms was 9.9 tonnes/ha (Pulver, Bejarano and Mendez, 2005). Participating farmers also began utilizing the technology and reported an average yield of 7.4 tonnes/ha. These yields are 3 to 5.5 tonnes/ha greater than the national average (Figure 5).

FIGURE 4
Yield in Costa Rica



African case study

The system of rice intensification (SRI) was developed in Madagascar in 1986 and has recently been spreading to Asia (Stoop, Uphoff and Kassam, 2002 and 2004; Stoop, 2003; Uphoff, 2005). SRI is based upon:

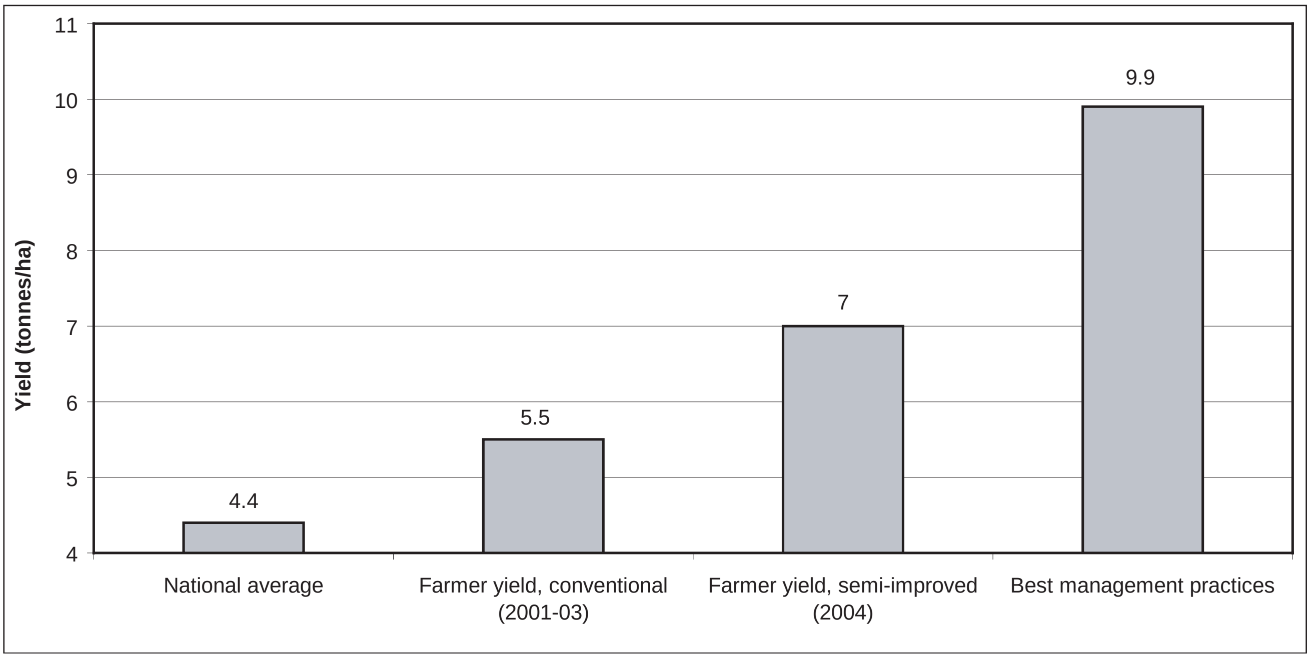
- early transplanting of clean seedlings;
- careful attention to transplanting to avoid root injury;
- transplanting at pre-determined spacing (0.25 × 0.25 m in unfertile soil and up to 0.50 × 0.50 m in fertile soil);
- frequent hand weeding before canopy closes;
- use of large amounts of compost or organic amendments; and
- intermittent irrigation to maintain the soil constantly moist during the vegetative stage followed by flooded conditions during reproduction.

The SRI system has been called unconventional, despite the fact that the technology employed has been well known for decades (Doberman, 2003; Sinclair, 1993; Sheehy *et al*., 2004). Use of high quality seed is known to provide a yield advantage of 10 to 15 percent; transplanting before the 4-leaf stage increases yield by approximately 16 percent (Balasubramanian *et al*., 2005); a weed-free environment is essential for high yields; and numerous sources of organic matter contain sufficient nutrients for high yields if applied in sufficient quantity.

Intermittent irrigation is feasible where it is possible to control weeds manually. It has been practised for decades in the Tolima area of Colombia and high yields are the norm, often exceeding 10 tonnes/ha. However, weed control costs often reach US$400/ha, due to dependence on chemical weed control and the need for repeated applications in the absence of flooded conditions to provide residual weed control. This does not appear to be a limitation for small farms, which are the focus of the SRI programme and where frequent hand weeding is feasible.

Management of inorganic N fertilizer (urea) is a major problem without the water control provided by flooded conditions. Ammonia volatilization is a huge problem with surface applications of urea; it can be significantly reduced by applying urea on the dry soil surface followed by establishment of a permanent flood to prevent nitrification/denitrification. In contrast, nutrients derived from the degradation of organic compost are essentially "slow release" with minimum losses. Some composted materials contain high levels of nutrients (e.g. chicken manure), and if applied in sufficient quantity they provide adequate nutrients to support high yields. However, not all compost is rich in nutrients, especially N. Given the wide variation in nutrient content of diverse compost, the SRI programme requires a more precise definition of suitable organic compost.

FIGURE 5
Yield in Nicaragua



Summary of case studies

The case studies from several countries in Asia, Latin America and Madagascar implemented under distinct socio-economic settings, employing different technologies and methods of transfer, have several features in common:

- High yields of irrigated rice are readily obtainable with improved crop practices utilizing current varieties. Yields in on-farm demonstration plots and commercial areas in southern Brazil routinely surpass 10 tonnes/ha and yields as high as 12.3 tonnes/ha have been obtained. Yields in Venezuela (Bolivarian Republic of) in the dry season often surpass 10 tonnes/ha in large areas. In Nicaragua, yields of over 12 tonnes/ha have been recorded in on-farm demonstration plots. In the Philippines, a yield of 11 tonnes/ha was recorded in demonstration plots using the PalayCheck technologies. Similarly, high yields often exceeding 8 tonnes/ha have been reported in lowland rainfed rice in Indonesia when grown under improved management. The SRI programme has also reported exceptionally high yields. An eminent rice scientist stated that the yield increases due to improved crop management are comparable to the yield advances experienced during the Green Revolution and referred to the advances occurring in crop management as the “Agronomic Revolution” in rice (Jennings, 2004).

- Observations from Asia and Latin American countries indicate that varieties are not the only limitation to improved yield. Currently available varieties are capable of yielding over 10 tonnes/ha and farmers are exploiting less than 50 percent of the yield potential of available genetic material. The yield gap – the difference between yield potential and actual yield – is due to lack of application of improved crop management practices. New genetic material will only be beneficial if accompanied by improvements in crop management; otherwise, yield expression will be limited by deficiencies in crop management, as has been the case since the Green Revolution. On the other hand, improved crop management offers the opportunity for plant breeders to develop genetic material with higher yield potential. For example, FLAR breeders, recognizing the yield limit of current varieties, have adjusted their breeding programme to focus on identifying genetic material with higher yield potential to link to improved crop management.

- High yields are more feasible in more favoured ecologies. Irrigated areas are easier to impact than less favoured ecologies; nevertheless, advances have also been reported in the lowland rainfed ecology. Within the irrigated sector, high yields are dependent upon adequate solar radiation. Yield advances are more frequently recorded during the dry season in the tropics or in temperate environments, where solar radiation is not a yield-limiting factor. Yield during the wet season in the tropics is limited, most probably due to low levels of solar radiation. All high-yielding environments, such as California, Australia, Egypt, coastal Peru and the southern cone of South America, also exhibit high levels of solar radiation. Under tropical conditions, adjusting the planting date to encounter high solar radiation during the critical phase of panicle initiation to flowering is one of the primary factors resulting in high yields reported in the case studies in Latin America.

- Focusing production during the dry season and under irrigation presents opportunities for alternative uses of land resources during the wet season and in less productive ecologies. At current rice prices, production during the low-yielding wet season and in stressed ecologies may often not be economically viable. Rice prices have been declining for decades and as production and consumption equalize, there will be more pressure for lower paddy prices (Dawe, 2004). The low level of return on labour in rice production often confines farmers to poverty. Use of simple water harvesting techniques permits production during the high solar radiation dry season. Alternative land use and income-generating practices are also required. Fish production may provide more income than rice during the wet season. Livestock rotated with rice is an attractive alternative in many areas and is already widely practised in the temperate regions of Latin America. In Asia, traditional thinking encourages rice production during the monsoon season since rice can tolerate excessive water.

However, further yield improvement during the wet season may be limited due to the low level of solar radiation. More thought is required to identify alternatives to rice farming during the solar-radiation-limiting wet season and other less favoured ecologies.

- To date, the efforts in integrated crop management have been carried out mainly by FAO and some government institutions in four Asian countries, by IRRI and institutions in India, and by FLAR in Latin America (as well as growers' associations in a number of countries). The transfer of SRI was carried out by conservation groups and NGOs. Traditionally, technological developments in rice were derived primarily from research activities at the CGIAR centres. The CG system may have over-emphasized variety development at the expense of crop management following the success of the Green Revolution, resulting in a missed opportunity and decades of yield stagnation, especially in the high-yield-potential irrigated system (Jennings, 2004).

Variety improvement merits sustained attention in order to address the yield potential barriers. Varieties with higher yield potential will be essential for a sustainable increase in rice production under conditions of diminishing land and water resources and taking into account the potential impacts of climate changes, such as high temperature regimes and increased area under tidal influence due to the rising sea level. The achievement of mapping the rice genome in 2002 creates new opportunities for the application of genetic resources in rice variety improvement by allowing scientists to identify and functionally characterize the genes and biochemical pathways that are responsible for agronomic performance, resistance to biotic and abiotic stress and consumer quality (Khush, 2004).

Outstanding issues in extension of crop management practices

Efficient and effective technology transfer programmes

The case studies provide convincing evidence that there are major differences between the transfer of improved crop management practices and simply introducing new varieties. Seed-based technologies are relatively easy to introduce and expand due to farmer-to-farmer exchange of seed. In contrast, improved crop management is "knowledge-based" and considerable effort is required to educate growers. Farmer-to-farmer exchange is often important but must be accompanied by a continuing educational process. Agronomic practices are not "fixed" like genetic traits and must be modified for different environments and frequently refined for distinct conditions within a particular farm. This requires in-depth knowledge of crop management by the farmer. How to teach millions of farmers with varying degrees of education remains a major challenge facing the rice sector.

Attention and resources have been directed towards the spread of high-yielding varieties. International germplasm testing programmes have been operative for decades. In contrast, there has been little attention to crop management and the identification of effective and efficient technology transfer programmes. The rice sector has limited knowledge of the farmer decision-making process, methods of educating growers, and means of sustaining extension activities, with the result that there is much "trial and error" in technology transfer. There are several examples of successful technology transfer programmes that are suitable for particular socio-economic settings, but it would be naïve to assume that systems developed in one particular country will function similarly in other countries with distinct socio-economic conditions. However, even with these limitations, there are concepts that may be applicable to successful technology transfer programmes. These universal concepts need to be more clearly identified, adjusted to particular socio-economic conditions and assembled into a structured extension service. It is recommended that the International Rice Commission and its partners take a lead role in defining more efficient and effective technology transfer programmes to extend the use of improved crop management practices.

Improved N management

N fertilizer is an essential ingredient for high yields in rice production. Increased costs for N-based fertilizer present a serious problem for advocating adequate N rates for high yields, and the environmental consequences of inefficient use are also a major concern. The problems associated with low N efficiency were highlighted at the 20th Session of the Commission. In Asia, FAO, IRRI and some member countries have promoted the use of the leaf colour chart for N top-dressing. Programmes in Latin America have incorporated practices to enhance high N fertilizer efficiency in the technology transfer efforts. SRI also places emphasis on more efficient N management through the use of organic compost. Technologies for N efficiency are available and need to be a component of all technology transfer programmes. In many African countries, high fertilizer prices make highly efficient management practices essential in order to compete with imported rice.

Research in crop management

Research in agronomy has not received the attention required; there is an imbalance in resource allocation which favours genetic improvement. This appears to be a consequence of the success of the Green Revolution, but the substantial decline in the growth rate of rice yield indicates that factors other than varieties are limiting yield. A host of factors require further research, for example, nutrient management for high yield, the role of climatic factors, date of planting, irrigation water management, and pest and disease control. Research on identifying improved crop management practices is out of date or lacking at both international and national level. Agronomic constraints to improved production are often erroneously thought to be “site specific”, precluding a concerted research effort at the international research centres. However, recent efforts show that the major constraints to improved crop management are widespread and it is inefficient to address the factors on a country-by-country basis without networking and sharing experiences.

TECHNICAL OPPORTUNITIES FOR SUSTAINABLE RICE PRODUCTION IN THE MEDIUM TERM (2006-10)

The current challenge is to find ways to continue increasing yields without putting pressure on the environment. Farmers who adopted high-yielding rice varieties obtained a major increase in yield but it was a one-time event; that is, once the new varieties were adopted, there was no subsequent yield increase.

The spread of rice cultivation into new areas, such as sub-Saharan Africa, presents yet another challenge to the scientific community. Even with the increased amount of land dedicated to rice, production has not kept pace with demand. This is further complicated by the low-input production systems in sub-Saharan Africa. Low input results in low yield and subsequently high-cost-per-unit output. With this scenario it is difficult for small, poor farmers to compete in the market place against cheaper imported rice. Some low-lying areas in Asian countries with monsoon rainfall patterns are not suited for growing anything but rice in the rainy season. Trends certainly indicate that the demand for rice will continue to grow, but the issue is how to maintain small farmers in rice production if yields are so low that they cannot compete in an open market situation.

Improved field management can result in significant yield increases, comparable to the advances witnessed during the Green Revolution. However, in order to improve management, farmers must be exposed to the new crop management technology and this implies considerable resources for extension and farmer training. In addition to the closing of the yield gap with efficient transfer of improved crop management practices, as discussed above, there are also readily available technical options for assisting rice farmers. The most prominent are described below.

Hybrid rice

Hybrid rice was first cultivated commercially in China in 1976 and yielded approximately 15 percent more than high-yielding varieties. Most recently, “super hybrids” have been developed that further increase yield by 20 percent. Hybrid rice increased annual production in China from about 128 million tonnes in 1975 to 191 million tonnes in 1990 (i.e. an increase of more than 60 million tonnes), while during the same period, the rice harvested area was reduced from 36 to 33 million ha. In 2004, more than 15 million ha in China and 1.5 million ha in other areas of Asia were planted with hybrid varieties. The area planted to hybrid rice in Asian countries outside China, however, represents only a small fraction of the total rice area (Table 5), indicating the major potential for adoption of hybrid rice to increase rice production.

Outside Asia, hybrid rice varieties have also been successfully developed and used in the United States (Way, 2004). Recently, hybrid rice varieties suitable for a subtropical climate have been successfully developed in Egypt (FAO, 2003b). However, the high price of F_1 seeds due to limited production remains a serious limitation to the widespread use of hybrids. Genetic uniformity and vulnerability remain a concern with current hybrids due to a common source of cytoplasmic male sterility.

New Rice for Africa (NERICA)

NERICA rice was developed by plant breeders at the Africa Rice Center (WARDA), combining African rice varieties already adapted to the local environment with Asian varieties that have high yield potential. NERICA is drought-tolerant and can increase yield by 30 percent over traditional African varieties (Jones and Wopereis-Pura, 2001; Defoer *et al*., 2004). Its short growing season (approximately 15 days shorter than that of other varieties) is especially important in sub-Saharan Africa where farmers can schedule their planting and harvesting to take advantage of the short rainy season in drought-prone areas. This also allows farmers to grow a second crop (e.g. legumes) that, when alternated with rice, helps maintain soil fertility. Although developed mainly for the rainfed uplands, researchers hope to develop other varieties of NERICA for irrigated and lowland systems. West and Central Africa boast some 20 million ha of inland valley swamps which are well suited for rice production, but less than 20 percent is used at present.

With the initial support of the United Nations Development Programme (UNDP), WARDA and FAO, the governments in sub-Saharan Africa established the African Rice Initiative (ARI) in 2002 to promote the dissemination of NERICA rice. Recently the African Development Bank approved a US$35 million multinational project for NERICA dissemination in sub-Saharan Africa (Akintayo, 2005). Also, the Government of Japan has approved funding support for FAO projects on the dissemination of NERICA and improved rice technologies in Ghana, Sierra Leone and Uganda.

Progress in advanced breeding and rice biotechnology

Advances in rice research and biotechnology are crucial for raising the yield potential of rice. The development of new plant type (NPT) and C-4 rice aims to increase the yield potential of tropical rice to about 12 to 13 tonnes/ha. Recent efforts have resulted in only limited success (Khush, 2004). FLAR breeders are now also developing new plant types with higher yield potential to respond to the advances in agronomy. These new types are based upon large panicles. Wide crosses involving wild relatives of *Oryza* offer promise for incorporating traits not found in *Oryza sativa* and perhaps increased yield potential (Khush, 2004). Recurrent selection strategies have also been used by a number of countries in Latin America and the Caribbean (LAC) for improving traits, such as cold tolerance, grain quality, disease resistance and yield potential. More than 20 broad genetic base populations with different characteristics have been created by national programmes; in 2002, Brazil released the first irrigated rice variety (SCSBRS 113-Tio Taka) out of a population breeding strategy, and in 2005, Bolivia released the second one. Breeding programmes in France and China already have population improvement as part of their breeding portfolio (Guimaraes, 2005).

The entire genome of rice has been sequenced and this has allowed the identification of thousands of DNA markers that are simple-sequence repeat (SSR), best known as microsatellite markers. Since the introduction of the modern high-yielding varieties, many breeding programmes have employed a genetically narrow gene pool. There are SSR markers available for many other

TABLE 5

General situation of the commercial hybrid rice cultivation in Asian countries outside China, 2002-04

	Hybrid rice area (*ha*)			National rice area (*million ha*)	% national area covered by hybrid rice
	2002	2003	2004	2004	2004
Viet Nam	500 000	600 000	650 000	7.40	8.8
India	200 000	290 000	560 000	42.50	1.3
Philippines	27 943	-	192 000	4.00	4.8
Myanmar	1 294	54 656	54 656	6.00	0.9
Bangladesh	-	-	40 000	11.00	0.4
Indonesia	-	-	875	11.70	n.a.
Sri Lanka	-	-	15	0.75	n.a.
Total	**-**	**-**	**1 497 546**		

Source: Nguyen, 2005.

traits, and there are numerous research programmes working to discover the function of rice genes. This type of information will allow the widespread development of single nucleotide polymorphisms (SNPs) – highly specific markers that are amenable to very high-throughput analysis.

Marker aided selection (MAS) is amenable to high-throughput analysis and sufficient polymorphism can be found for the parents of most crosses, enabling breeding to expand the genetic base (Coffman, McCouch and Herdt, 2004). Several molecular markers for disease and pest resistance are available, including markers for both major and minor resistance genes for rice blast, rice bacterial blight (*Xanthamonas oryzae*) and planthopper. Rice hoja blanca is an important disease in LAC and is costly to screen in the field. Already one potential marker has been identified for resistance to this disease. The MAS technologies are being used in only a few advanced laboratories. As more information on resistance to biotic and abiotic stresses (as well as on important agronomic characteristics) emerges, the use of MAS will become more compelling. The question is not will MAS become an important standard activity in rice breeding programmes, but when will it be economical to employ the technology in high-volume rice breeding programmes?

Rice does not normally produce vitamin A and "Golden Rice" was developed to alleviate vitamin-A deficiency. It was developed by inserting two daffodil genes and one bacterial gene into the rice genome. This allows the production of beta-carotene in rice grain. The resulting plants are normal except that their grain is a golden-yellow colour due to the presence of provitamin A (Potrykus, 2003).

Rice hoja blanca virus (RHBV) is a major viral disease of economic importance affecting rice in northern South America, Central America and the Caribbean. Transgenic plants with the RHBV nucleoprotein viral gene are available and have been crossed with the commercial variety, Fedearroz 50 (Lentini *et al.*, 2003). Field evaluations indicated that six fixed, transgenic lines were more resistant than Fedearroz 2000, the most RHBV-resistant commercial variety. The transgenic lines express low levels of RNA, which is detectable only by RT-PCR, and the RHBV nucleoprotein is not expressed in these plants, thus suggesting a very low risk, if any, for environmental and food safety concerns.

While the deployment of transgenic rice varieties for commercial production is still limited, there are many field experiments throughout the world. Herbicide resistance and stem borer resistance (Bt) are widely deployed in commercial cotton, maize and soybean. Herbicide resistance using mutants which are not transgenic is currently used on a wide scale in southern Brazil, the United States and parts of Colombia and Costa Rica. Mutant herbicide resistance offers the opportunity to effectively control red rice, a major problem throughout LAC. New herbicide resistance based upon transgenic technology will soon be available, but commercialization remains a question. Resistance to abiotic and biotic stresses using genetic transformations continues to be pursued by several laboratories.

Commercial use of the new technology is complicated by:

- issues of intellectual property rights;
- public acceptance of GMOs; and
- difficulties involving the trade of transgenic material.

The technology is much more advanced than is public acceptance and perception; advanced breeding and biotechnology methods are available. However, the results of an FAO study show the need for urgent capacity building in developing countries, if full advantage is to be taken of the new technologies.

THE WAY FORWARD

The advances in crop management and corresponding large yield increases reported by various organizations in different countries and continents present new opportunities, especially in the irrigated sector. Technological factors and methods per se do not appear to be the primary factor limiting production increases but deficiencies in application of technology transfer hinder the spread of known technologies to large numbers of farmers. There are diverse methods of technology transfer. Several programmes are operative using different methodologies and strategies and involving a range of institutions/agencies. New partnerships are evolving that offer unique opportunities. Development of appropriate technology transfer systems for distinct socio-economic settings involving a range of actors represents the next challenge in the rice sector.

Higher yields and lower production costs with minimum harmful effects on the environment are imperative for more competitive production in a global market that is increasingly environmentally sensitive.

Improved crop management can result in significant yield and production increases on less land and with less water. This offers the opportunity for diversification of rice-based systems, for example, rotation of rice with fish, rice with livestock, rice with a range of other crops in order to spread risk but also to increase income and to improve human nutrition. New paradigms are emerging that require innovative ideas in technology transfer, more efficient use of resources and alliances with new partners.

As the yield gap in rice production is narrowing with improved crop management, a new generation of rice varieties will be needed for sustainable rice production. The progress in plant breeding and rice biotechnology should be harnessed for generating rice varieties with not only high yield potential but also good taste, eating quality and added nutrients. This will require a broad and strengthened partnership among international institutions, public institutions, the private sector and non-governmental organizations.

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Amélioration de la production rizicole dans un contexte en évolution: de la théorie à la pratique

Depuis la dernière réunion de la Commission internationale du riz, qui s'est tenue en 2002 à Bangkok (Thaïlande), plusieurs faits marquants ont été enregistrés dans le sous-secteur du riz: l'Assemblée générale des Nations Unies a adopté la Résolution 57/162 proclamant 2004 l'Année internationale du riz; en 2002 la production mondiale de riz a commencé à nouveau à progresser après trois années consécutives de recul; enfin en 2005, le rendement mondial moyen a dépassé le seuil des 4 tonnes à l'hectare. On relève aussi des facteurs négatifs. La production rizicole en Afrique subsaharienne continue à être inférieure à la consommation. Une utilisation excessive de l'eau, une dégradation environnementale due à la contamination par les pesticides et les éléments nutritifs, les émissions de méthane et la volatilisation de l'ammoniaque sont parmi les risques liés à la production de riz qu'il convient de traiter d'urgence. Les ressources en terre et en eau nécessaires à la production rizicole diminuent et les changements climatiques mondiaux peuvent avoir des répercussions importantes sur la production de riz.

Plusieurs recommandations ont été formulées aux dernières sessions de la Commission internationale du riz, notamment pour ce qui est de la promotion des techniques améliorées de cultures lors de la vingtième session (en Thaïlande) et de la Consultation d'experts sur les écarts de rendements et la chute de la productivité dans la production de riz (Italie, septembre 2000). Les études de cas relatives à plusieurs pays d'Asie et d'Amérique latine ainsi qu'à Madagascar, effectuées dans divers contextes socio-économiques et en utilisant des techniques et des méthodes de transfert différentes, ont montré qu'il est facile d'obtenir des rendements élevés pour le riz irrigué en utilisant des pratiques culturales améliorées appliquées aux variétés courantes. Les pratiques de culture améliorées ont permis d'obtenir des rendements plus élevés et une réduction des coûts de production, tout en limitant les effets néfastes pour l'environnement, ce qui est essentiel pour stimuler la compétitivité sur un marché mondial de plus en plus sensible aux questions liées à l'environnement. Toutefois, afin d'améliorer la gestion, les agriculteurs doivent connaître les nouvelles technologies de gestion ce qui nécessite des ressources considérables destinées à la vulgarisation et à la formation des agriculteurs.

Les agriculteurs peuvent avoir facilement accès au riz hybride et aux variétés NERICA. Le riz hybride a été cultivé pour la première fois en Chine, en 1976, et a permis d'obtenir un rendement supérieur d'environ 15 pour cent à celui des variétés à haut rendement. En 2004, les variétés hybrides ont été cultivées sur plus de 15 millions d'hectares en Chine et sur 1,5 million d'hectares dans d'autres régions d'Asie.

Le riz NERICA a été obtenu par l'Association pour le développement de la riziculture en Afrique de l'Ouest (ADRAO) en associant des variétés de riz africain déjà adapté à l'environnement local à des variétés asiatiques dont le rendement potentiel est élevé. Le riz NERICA résiste à la sécheresse et sa période de croissance est courte (environ 15 jours de moins que les autres variétés) caractéristique très importante en Afrique subsaharienne, car les agriculteurs peuvent ainsi planifier les semis et la récolte pour tirer parti de la brève saison des pluies dans les zones exposées à la sécheresse.

Comme l'écart de rendement dans la production de riz diminue avec une meilleure gestion des cultures, il est nécessaire d'obtenir de nouvelles variétés permettant une production de riz durable. Les progrès accomplis par la sélection végétale et les biotechnologies appliquées au riz devraient permettre de créer des variétés dotées non seulement de rendements potentiels élevés aussi de qualités gustatives et nutritionnelles. À cet effet, il sera nécessaire d'élargir et de renforcer les partenariats entre les institutions internationales, les institutions publiques, le secteur privé et les organisations non-gouvernementales.

Mejorar la producción del arroz en un entorno cambiante: del concepto a la práctica

Desde la última reunión de la Comisión Internacional del Arroz, celebrada en Bangkok (Tailandia) en 2002, se han producido acontecimientos notables en el subsector del arroz. La Asamblea General de las Naciones Unidas aprobó la Resolución 57/162, en la que se declaró el año 2004 como Año Internacional del Arroz. La producción mundial de arroz comenzó a aumentar nuevamente en 2002 después de tres años consecutivos de descenso y en 2005 el rendimiento medio mundial se sitúa por encima de la barrera de las 4 toneladas/ha. Sin embargo, el sector del arroz también se ve aquejado por factores negativos. En el África subsahariana, el consumo de arroz sigue superando la producción. El uso excesivo de agua, el deterioro ambiental debido a la contaminación por plaguicidas y nutrientes, las emisiones de gas metano y la volatilización del amoníaco son algunos de los efectos perjudiciales de la producción del arroz que requieren atención urgente. Los recursos de tierras y aguas para la producción del arroz disminuyen y los cambios climáticos mundiales podrían tener efectos de gran alcance en esta producción.

En las últimas reuniones de la Comisión Internacional del Arroz (CIA) se formularon varias recomendaciones, en especial la relativa al fomento de tecnologías mejoradas de gestión de cultivos, formulada en la 20ª reunión, celebrada en Tailandia, y en la Consulta de expertos sobre el déficit de rendimientos y el descenso de la productividad en el sector arrocero, celebrada en Italia en septiembre de 2000. Los estudios monográficos de varios países de Asia, América Latina y Madagascar, realizados en diferentes entornos socioeconómicos y empleando técnicas y métodos de transferencia distintos, han señalado que pueden obtenerse fácilmente rendimientos elevados del arroz de riego con prácticas de cultivo mejoradas que utilizan las variedades actuales. La mejora de las prácticas de gestión de los cultivos se tradujo en un aumento de los rendimientos y en la reducción de los costos de producción con unos efectos perjudiciales mínimos en el ambiente, lo cual resulta obligatorio para conseguir una producción más competitiva en un mercado mundial cada vez más sensibilizado con el medio ambiente. No obstante, para mejorar la gestión es necesario que los agricultores se familiaricen con la nueva tecnología de gestión de cultivos, lo cual conlleva dedicar una cantidad importante de recursos a la extensión y la capacitación de los agricultores.

Para ayudar a los agricultores de arroz, también son fácilmente asequibles las variedades de arroz híbrido y de NERICA. El arroz híbrido se cultivó por vez primera para su comercialización en China en 1976 y sus rendimientos fueron casi un 15 % mayores que los obtenidos con variedades de alto rendimiento. En 2004, se plantaron variedades híbridas en más de 15 millones de hectáreas en China y en 1,5 millones de hectáreas de otras zonas de Asia.

Fitogenetistas del Centro Africano del Arroz (ADRAO) obtuvieron la variedad NERICA combinando variedades de arroz africanas ya adaptadas al entorno local con variedades asiáticas de elevado rendimiento potencial. La variedad NERICA tolera la sequía y su breve período de crecimiento, unos 15 días menos que el de otras variedades, reviste especial importancia en el África subsahariana, donde los agricultores pueden programar su plantación y cosecha para aprovechar la estación de las lluvias cortas en zonas propensas a la sequía.

Dado que la mejora de la gestión de cultivos reduce la brecha de rendimientos en la producción del arroz, es preciso obtener una nueva generación de variedades de arroz a fin de conseguir la producción sostenible del arroz. Los avances logrados en el fitomejoramiento y la biotecnología del arroz deberían aprovecharse para generar variedades de arroz que no sólo tengan un elevado rendimiento potencial, sino también buen gusto, calidad alimentaria y nutrientes añadidos. Para ello será necesario que instituciones internacionales, instituciones públicas, el sector privado y organizaciones no gubernamentales amplíen y refuercen su colaboración.

Rice contribution to food outlook[1]

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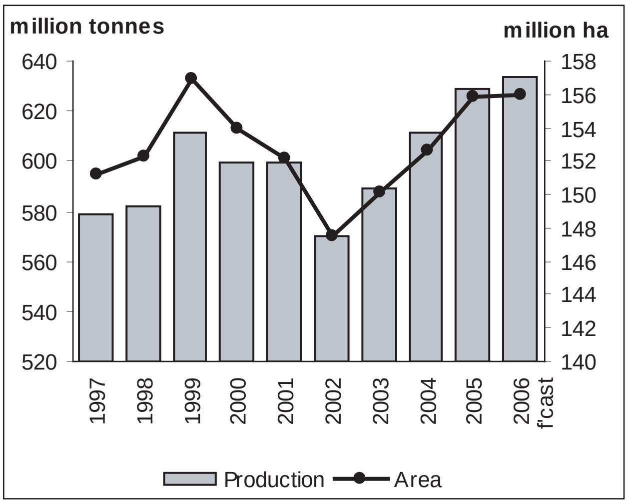
PRODUCTION

Outlook for global paddy production in 2006 positive, but falling profitability could dampen rate of expansion of the sector

The 2006 paddy season started on the trail of an excellent 2005 season, which saw paddy production rise by more than 3 percent to an all-time high of 631 million tonnes (421 million tonnes, milled basis). This outcome reflected the favourable growing conditions in most parts of the world, but also the generally attractive price conditions that prevailed in 2004 and which prompted a general expansion of planting. In addition, governments in several countries continued to provide support to the sector with the objective of achieving self-sufficiency in the medium term.

The 2006 paddy season is already well advanced south of or along the equator where, by May, many countries are already harvesting their main paddy crop. In the Northern Hemisphere, the main 2006 crops are still at the development stage in parts of Asia, Africa, Europe and North America, while they are not even in the ground in countries such as India or the Philippines, where the opening of the season coincides with the arrival of the southwest monsoon around June. This represents a major element of uncertainty for the 2006 production outlook – uncertainty that will persist until at least August, when more will be known about the timing and distribution pattern of the monsoon rains.

FIGURE 1
Global rice paddy production and area



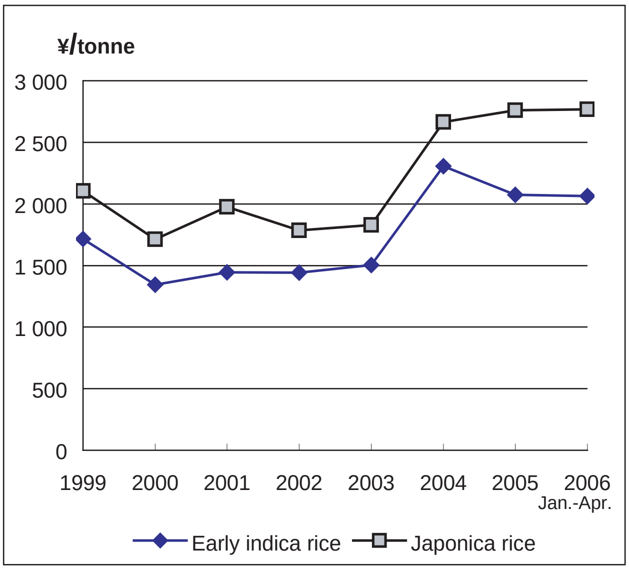
Although still tentative, the FAO forecast for global paddy production in 2006 currently stands at 635 million tonnes (only 0.8 percent, or 4 million tonnes, more than last season). This rather subdued outlook reflects the concerns over rising production costs and uncertain price prospects.

In the Southern Hemisphere (where the 2006 season is fairly advanced), production is estimated to increase in Argentina, Australia, Indonesia, Madagascar and Ecuador, while the outlook is negative for Brazil, Peru, Uruguay and Sri Lanka. However, most of the expected growth in global production is likely to originate in the major producing countries situated north of the equator, in particular Bangladesh and China. In Bangladesh, strong domestic demand for rice and the maintenance of high subsidies on petroleum prices are likely to sustain growth, while in China, relatively attractive market prices (especially for high quality rice) and continued government support are expected to sustain the recovery of the sector initiated in 2004.

Assuming a normal monsoon, an increase in production is forecast in India and the Philippines; however, this outlook is surrounded with uncertainty. Production prospects are positive in Thailand and Viet Nam (the two major rice-exporting countries) and also in Nigeria (a major importer), where the government is actively promoting expansion of the sector. In contrast, production is forecast to fall in Japan, where exceptionally favourable conditions boosted yields in 2005 and thwarted government efforts to cut excess supplies. The outlook is negative also in Pakistan, where insufficient rainfall and water shortages at sowing time delayed plantings. Similarly, the USDA (United States Department of

[1] The information contained in this article is of June 2006.

FIGURE 2
Rice market prices (China)



Agriculture) forecast points to a reduced crop in the United States, especially for long-grain, *indica* rice varieties, reflecting a marked reduction in the area prompted by high fuel prices and damage from hurricanes in 2005.

INTERNATIONAL TRADE

Following record high in 2005, international trade in rice may decline in 2006, still striking second best performance on record

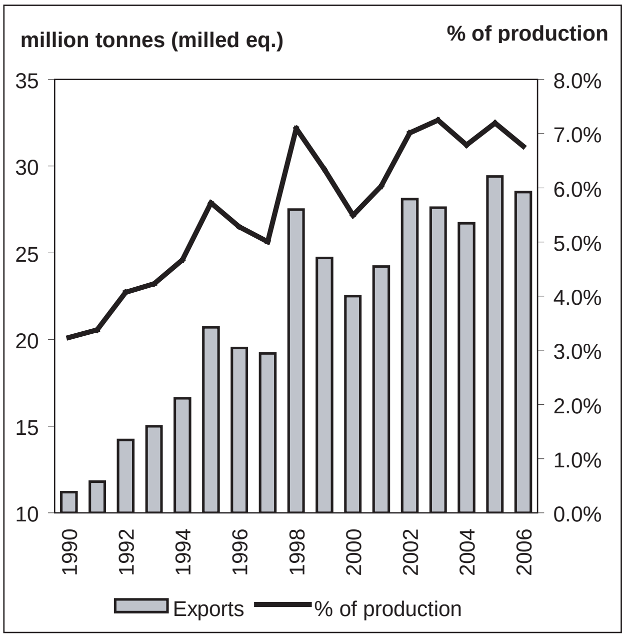
In 2005, rising import demand from countries in Africa and Asia provided a major stimulus to the rice trade, which rose to an all-time high of 29.4 million tonnes. The expansion took place in spite of a reduction in exports from Thailand and China, the shortfalls of which were more than compensated for by a surge of shipments from India, Pakistan and Viet Nam.

FAO currently anticipates a 2.5 percent reduction in the world rice trade in 2006 to 28.6 million tonnes – nevertheless the second highest level on record. Following the exceptional 2005 trade performance, the drop is anticipated as a result of the general reduction in import demand by African countries, where good crops were harvested in 2005. Much of the reduction is on account of Nigeria, where shipments are forecast to drop from 2.0 to 1.6 million tonnes, reflecting the imposition of a ban on milled rice imports since the beginning of 2006. Though falling, shipments to Côte d'Ivoire, Senegal and South Africa are likely to remain large (in the order of 800 000 tonnes), with imports from all African countries expected to reach some 9.2 million tonnes (32 percent of the world total), down from 10.1 million tonnes in 2005.

Deliveries to Asian countries are forecast to remain very close to last year's level of 13.4 million tonnes, despite smaller anticipated deliveries to Bangladesh, the Democratic People's Republic of Korea and the Philippines, where record crops were harvested in 2005. Purchases by the Islamic Republic of Iran, on the other hand, are anticipated to surge: given the tensions on the international front, the country is increasing imports in an attempt to build up reserves. Purchases by China are also likely to rise, following trade agreements signed in 2005 with several exporting countries and given the growing domestic demand for quality rice. Iraq, the Republic of Korea, Saudi Arabia and Turkey are also expected to import more this year. In Indonesia (one of the major traditional rice markets), government restrictions currently extended until June 2006 are likely to keep imports in 2006 at around the 2005 level of 600 000 tonnes.

Overall, shipments to countries in Latin America and the Caribbean are expected to rise slightly compared with 2005, reflecting a recovery in imports by Brazil as a result of this season's production shortfall. In contrast, imports by Peru may fall, while little change is expected in imports

FIGURE 3
World rice trade (in volume and as share of global production)



directed to the other countries in the region. On the policy front, it is worth noting the implementation in 2006 of the free trade agreement (FTA) signed between the United States and six countries in Central America and the Caribbean (Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras and Nicaragua). The FTA granted rice long transition periods of between 18 and 20 years for the complete elimination of border tariffs; therefore, no major immediate impact on the volume of imports of the member countries is expected, but traditional suppliers may be displaced as the United States gain access thanks to the duty-free quota (Table 1).

FTAs were also signed earlier this year between the United States and Colombia and between the United States and Peru, but they have not yet been ratified by the countries' parliaments.

In the rest of the world, imports by the United States are officially forecast to rise strongly. In the European Union (EU), the reform of the rice import system – with a marked reduction in duties on husked rice and milled rice imports – may result in a higher level of rice deliveries to the EU in 2006. Under the new regime, milled rice will be subject to duty of either 145 or 175 euros per tonne and husked rice to duty of 30, 42.5 or 65 euros per tonne, depending on the actual level of imports. In contrast, purchases by the Russian Federation might fall, following the bumper crop harvested last season.

In terms of exports, the expected fall in international trade in 2006 will be due to smaller shipments from those countries that witnessed a surge in 2005, in particular India, which shipped an estimated 5.3 million tonnes last year, second only to Thailand. In 2006, India's rice sales are forecast to be much smaller – in the order of 4.4 million tonnes – as large government procurement purchases are reported to have lifted prices of rice (with the exception of parboiled rice) above other competitors' levels. Exports from Egypt, Pakistan, the United States and Uruguay may also decline, as the four countries face tightening of supplies in 2006. Thailand's competitiveness has been eroded since April: the strength of the Baht relative to the US dollar, combined with the government rice-pledging scheme, has contributed to a rise in export quotations, resulting in a 4 percent reduction in shipments in the first quarter of 2006. However, strong sales to the Islamic Republic of Iran and Iraq and government-to-government deals are likely to enable the country to maintain exports at around last year's volume of 7.5 million tonnes. Viet Nam's shipments are currently forecast to remain in the order of 5.2 million tonnes (the government's set target), especially as availability from the 2005 season will be less – a factor which may prompt the government to impose intermittent restrictions on exports again in 2006. On the other hand, shipments from China, which remain under government control, may

FIGURE 4
Rice imports, by region

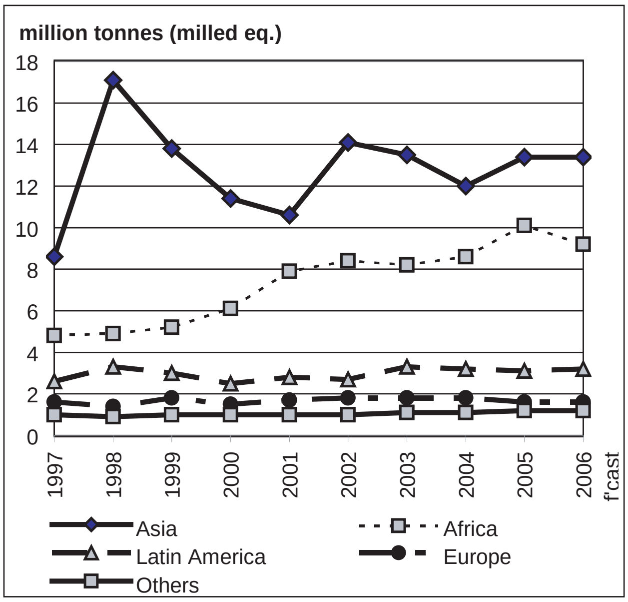
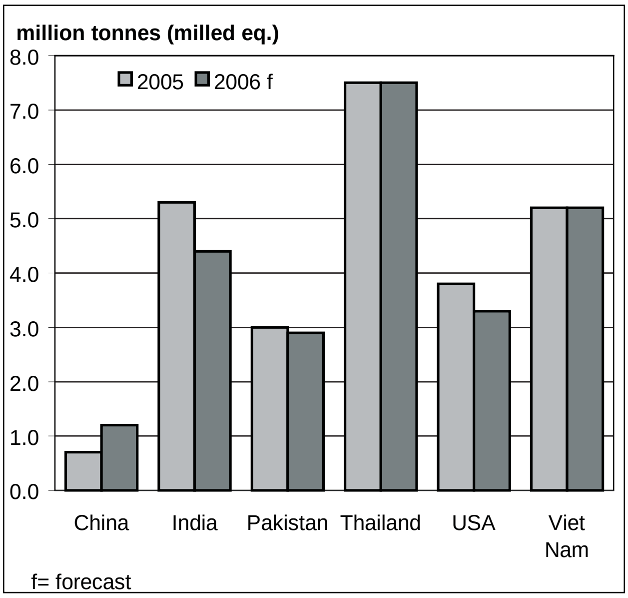


TABLE 1
Rice duty-free quota to the United States (first year of implementation, 2006)

	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua	Dominican Republic	**Total**
Paddy rice	51 000	62 220	54 600	91 800	92 700	2 140	**354 460**
Milled rice	5 250	5 625	10 500	8 925	13 650	8 560	**52 510**
Total rice quota (milled rice equivalent[a])	**38 400**	**46 068**	**45 990**	**68 595**	**73 905**	**9 951**	**282 909**

[a] Paddy rice converted into milled rice by applying a standard multiplying factor of 0.65.
Source: CAFTA, FAO.

FIGURE 5
Rice exports by the major exporters



rebound somewhat. Similarly, the end of the drought and the ensuing production recovery in 2006 should enable Australia to recapture some of the markets lost over the past 4 years. In Latin America and the Caribbean, sales by Argentina are expected to rise, especially in view of an expected rebounding of imports by Brazil and higher prices from the United States, a major competitor in the region.

GLOBAL RICE UTILIZATION

Under current prospects for modest growth in global production in 2006, rice utilization in 2006/07 not sufficient to prevent per caput consumption from falling

Given the relatively high costs of production, rice remains essentially a food commodity, with only a small share of supply destined for feed, except on farms. Large gains in production in the 2005 season are estimated to have boosted global rice utilization, even allowing a small increase in per caput rice consumption from 56.9 kg in 2004/05 to 57.1 kg in 2005/06. However, this gain was mainly concentrated in developed countries, where per caput demand has been following a marked upward trend in recent years. Per caput rice availability remained unchanged (at around 68.7 kg) for developing countries as a whole and even declined for low-income food-deficit countries (LIFDCs).

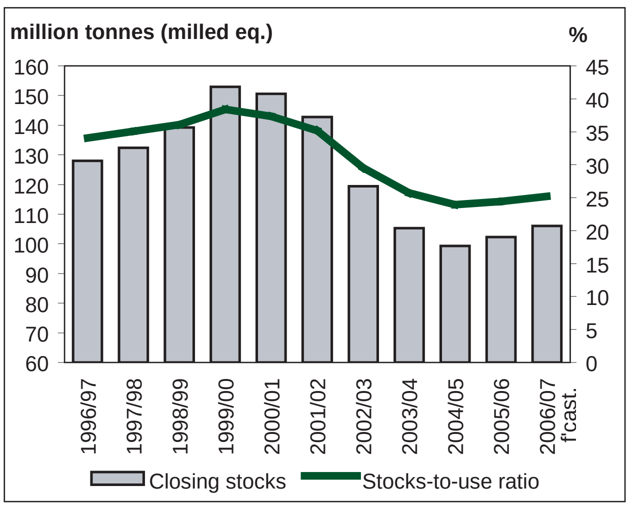
Tentative forecasts indicate that world rice utilization will increase marginally in 2006/07, on the basis that limited gains in production are expected in 2006. Availability of rice for food consumption will be lower with a fall in average per caput availability to 56.9 kg. All country groupings, including LIFDCs, would be affected.

CLOSING RICE INVENTORIES

Rebuilding of global rice inventories initiated in 2005 likely to progress in 2006

World rice inventories at the close of the 2005/06 marketing season are estimated to reach 102 million tonnes (up from 99 million tonnes in the previous year). Production in the 2005 season would thus be sufficient to meet consumption needs at a slightly higher average per caput level and global rice reserves (falling since 2000) could be rebuilt. Stocks in China – the country that has driven much of the recent downscaling of global rice inventories – ended higher, reflecting growth in production and a lingering tendency for per caput rice demand to weaken. Production increases in 2005 also facilitated a rebuilding of inventories in Bangladesh, Cambodia, the Islamic Republic of Iran, Myanmar and Thailand. On the other hand, carryovers are estimated to have fallen below their opening level in Indonesia and Viet Nam. In Africa, the anticipated drop in imports in 2006 contributed to a fall in end-of-season stocks in most countries. This was the case in Egypt, where reserves were consumed in order to meet the strong domestic and export demand. The larger crops harvested in 2005 in South America allowed some rebuilding of rice reserves

FIGURE 6
Global rice closing stocks and stocks-to-use ratio



in the subregion, in particular, in Brazil and Peru. Among developed countries, inventories increased in Japan and the United States.

Preliminary forecasts for closing rice inventories at the end of the 2006/07 marketing season point to a continuation of the stock rebuilding process initiated in 2005, with global rice inventories expected to rise to 106 million tonnes. Most of the increase, however, is likely to be concentrated in China, with larger reserves of rice also foreseen in Thailand. Stocks in most of the other countries could end lower, including those held by major rice exporters, in particular India and the United States.

INTERNATIONAL PRICES

Buoyant international rice prices in the first months of 2006

International prices in the first 4 months of 2006 were remarkably buoyant. The FAO rice price index, which had been stable at 101 from June to December 2005, rose to 103 in January 2006, to 105 in February and to 106 in both March and April 2006. Prices remained high in the first 2 weeks of May, when the index reached 107.

Ordinary and parboiled *indica* had particularly good prices, thanks to large purchases by countries in Asia, notably Iraq, the Islamic Republic of Iran and the Philippines. The launching of import tenders by Japan and the Republic of Korea also tended to lift *japonica* rice quotations. On the other hand, quotations of lower quality *indica* tended to weaken compared with the end of 2005, to some extent reflecting the retrenchment of African buyers. The general strengthening of international rice prices in the first quarter of the year also reflected the effects of government procurement programmes with relatively high prices in Thailand and India and a tightening of export availability in some major exporting countries, including Pakistan, the United States and Viet Nam. In addition, the strengthening of the Thai Baht relative to the US dollar (in which export prices are expressed) further contributed to the buoyancy of price quotations since April.

World rice prices in the next few months are expected to remain firm, although much will depend on the policies of the major international trade players, in both export and import. Given the prevailing stance of governments in Thailand and Viet Nam to keep prices from falling and limited export from alternative sources (including Australia, India, Pakistan and the United States), rice quotations are expected to make further gains at least until August/September when several Northern Hemisphere countries will start harvesting their main 2006 crops.

Contribution relative au riz parue dans les perspectives de l’alimentation

Les perspectives actuelles concernant la production de paddy de 2006 font état d’une croissance modeste du fait des préoccupations liées aux coûts de production croissants et à la moindre rentabilité. Toutefois, ces indications ont un caractère provisoire, du moins jusqu’en août, époque où l’on en saura plus sur le comportement des pluies de mousson en Asie. Après avoir atteint un volume record en 2005, les échanges de riz pourraient se contracter pendant l’année en cours, car les importations à destination des pays africains – principal moteur de croissance au cours de la décennie passée – devraient reculer. La reconstitution des stocks de clôture, qui s’est amorcée en 2005-06, devrait se poursuivre pendant la campagne en cours, processus qui concerne essentiellement la Chine.

Les gains de production devant être limités, la disponibilité par habitant de riz destinée à la consommation devrait reculer en 2006/2007. Les cours mondiaux du riz, qui ont été particulièrement florissants au cours du premier trimestre de 2006, devraient rester fermes ces prochains mois.

La aportación del arroz a las perspectivas alimentarias

Debido a las inquietudes que suscitan el aumento de los costos de producción y la disminución de la rentabilidad, las perspectivas actuales para la producción de arroz en 2006 no apuntan sino a un crecimiento moderado. No obstante, se trata de perspectivas que han de considerarse provisionales al menos hasta agosto, cuando se tengan más datos sobre las modalidades de las lluvias monzónicas en Asia. Tras el nivel sin precedentes alcanzado en 2005, el comercio del arroz podría debilitarse durante el año, al disminuir las importaciones de los países africanos, que en el decenio pasado constituyeron el motor principal de su crecimiento. Es probable que en la campaña actual prosiga la reposición de las existencias arroceras iniciada en 2005/06 y concentrada principalmente en China.

Dadas las expectativas de que se produzca un aumento moderado de la producción y de la reposición de las existencias arroceras, es posible que en 2006/07 disminuya la disponibilidad per cápita del arroz destinado al consumo humano. Los precios internacionales del arroz, que en el primer trimestre de 2006 eran particularmente firmes, deberían mantenerse estables en los meses venideros.

Summary report of the 21st Session of the International Rice Commission

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The FAO Conference, at its Fourth Session in 1948, established the International Rice Commission (IRC), with the objective of promoting national and international action in matters relating to the production, conservation, distribution and consumption of rice. The Commission's Constitution went into force in 1949. Its member countries have since grown from 15 in 1949 to 61 at present. Every 4 years, the IRC organizes a session to review the emerging issues and recent achievements in scientific, technical and socio-economic matters relating to sustainable rice production. Furthermore, it assists member countries in orienting strategies for their national rice development programmes while encouraging extensive interaction among national, regional and international institutions.

The 20th Session of the IRC was convened in Bangkok, Thailand, in 2002. The 21st Session of the IRC was convened at the Gran Chiclayo Hotel, Chiclayo, Peru, from 3 to 5 May 2006 by the Ministry of Agriculture of Peru and FAO. The main theme was "Rice is Life – Bringing the Implementation of IYR to Farmers' Fields". It was attended by 90 delegates and participants from member countries and partner institutions. There were five subsessions, a poster session and a field visit.

MAIN OBSERVATIONS

The Commission *noted* the following:

- In December 2002, the United Nations General Assembly (UNGA) at its 57th Session, noting that rice is the staple food of more than half of the world's population and reaffirming the need to focus world attention on the role that rice can play in providing food security and eradicating poverty, declared 2004 the International Year of Rice (IYR).
- The Second Committee of the 60th Session of the UNGA in November 2005 recognized the success and the contribution of the implementation of the International Year of Rice in 2004 in effectively raising awareness of the role that rice plays in reducing hunger and poverty and the support of all stakeholders for sustainable rice production.
- Rice supplies consumers with more calories than other staple crops, particularly in the diets of very poor people whose food purchases account for more than half of all expenditures. Women and children in sub-Saharan Africa, South and Southeast Asia, and Latin America and the Caribbean are especially susceptible to deficiencies in micronutrients, in particular vitamin A, iron and zinc.
- For the third consecutive year, global paddy production experienced a brisk expansion in 2005, lifting total production to a record 629 million tonnes. However, the increase in global production in 2005-06 will be only just sufficient to cover utilization.
- Rice production in sub-Saharan Africa continues to be outpaced by consumption, while food insecurity and poverty are extensive in rainfed rice ecosystems in Asia where the demand for food has been growing fast.
- The world population continues to increase steadily, while land and water resources for rice production are diminishing due to competition from other sectors of the economy and the growing population. Moreover, the environment and natural resource bases of rice production are being degraded due to pesticide and nutrient contamination.
- The increased temperature, rising seas and erratic rainfall distribution under global climate change have potentially large negative impacts on the productivity of rice farming.
- Pilot tests conducted by FAO, member countries and partner institutions have demonstrated the effectiveness of rice integrated crop management (RICM) systems in closing the rice yield gap (i.e. the difference between the yield potential of existing varieties and the yields which are actually obtained by farmers), increasing farmers' profits and minimizing damage to the environment.

- After the development of high-yielding varieties, hybrid rice and NERICA (New Rice for Africa) rice are the two major achievements in the field of rice breeding. In 2004, about 1.5 million ha of hybrid rice were planted in a number of Asian countries, in addition to about 15 million ha of hybrid rice in China. In sub-Saharan Africa, NERICA rice is being adopted by farmers.

MAIN RECOMMENDATIONS

The Commission *recommended* the following:

- Member countries, funding donors, FAO, partner institutions and all stakeholders should increase collaborative efforts and funding support to activities aimed at full implementation of the Commission's recommendations for the sustainable increase in rice production to reduce hunger and poverty.
- The partnership in rice research and development between national and international institutions, as well as NGOs (non-governmental organizations) and the private sector, should be strengthened and broadened for effective contribution to the sustainable increase in rice production in member countries.
- Rice production systems should be viewed in an integrated way, from seed selection to food on the table, taking into account the interaction and relationships among rice plants and other organisms in the rice ecosystems, in order to maximize income and nutrition enhancement and to conserve natural resources for future production.
- Strategies and policies for sustainable rice production should aim to build the capacity of rice farmers in precision management in order to: improve the efficiency of resource utilization (especially water), reduce environmental damage and enhance the economic competitiveness of rice production systems. Guidelines and criteria for monitoring the sustainability of rice production systems should therefore be developed for each of the rice agro-ecologies in order to facilitate farmer training.
- Efforts to improve human nutrition should include initiatives to: promote the development, dissemination and adoption of rice varieties with a high content of iron, zinc and vitamin A; raise consumer awareness; and obtain support from industry.
- Variety development should focus not only on high yield, but also on increased nutritional value and improved tolerance to salinity, high temperature, drought and flood stress.
- Small and medium-size enterprises that harness technologies for transforming the whole rice grain – including milled rice, rice bran and rice husks – into value-added products should be promoted in order to increase the returns from rice production and to open up employment opportunities.
- The Secretariat of the Commission should organize a Global Expert Consultation, between the 21st (2006) and 22nd (2010) Sessions, in order to review progress and identify suitable strategies for upscaling the transfer of rice integrated crop management systems for closing the yield gap, increasing profit and reducing environmental degradation in rice production under different agro-socio-economic set-ups.

DATE AND PLACE OF THE NEXT SESSION

The Commission expressed appreciation for the invitation extended by the delegation of France to host the 22nd Session in 2010. The final decision as to the exact date and place shall be made by the Director-General of FAO, in consultation with the Government of the member country concerned.

Résumé du rapport de la vingt et unième session de la Commission internationale du riz

La Conférence de la FAO, à sa quatrième session en 1948, a établi la Commission internationale du riz (CIR), dont l'objectif est de promouvoir les initiatives nationales et internationales visant la production, la conservation, la distribution et la consommation de riz. L'acte constitutif de la Commission est entré en vigueur en 1949. Ses États membres sont passés de 15 en 1949 à 61 à l'heure actuelle. Tous les quatre ans, la Commission organise une session pour examiner les nouveaux développements et les réalisations récentes dans les domaines scientifique, technique et socio-économique pour ce qui est de la production durable. En outre, elle aide les États membres en orientant les stratégies de leurs programmes nationaux de mise en valeur du riz tout en encourageant une interaction massive entre les instituts nationaux, régionaux et internationaux.

La vingtième session de la Commission s'est tenue à Bangkok (Thaïlande) en 2002. La vingt et unième session de la CIR a été organisée au Gran Chiclayo Hotel à Chiclayo (Pérou), du 3 au 5 mai 2006 par le Ministère de l'agriculture du Pérou et la FAO, autour d'un thème central: “Le riz c'est la vie - Mettre en œuvre les apports de l'Année internationale du riz dans les petites exploitations”. Quatre-vingt dix délégués et participants provenant des États membres et des institutions partenaires étaient présents. Ils ont assisté à cinq sous-sessions, à une séance de démonstration et à une visite de terrain.

Principales observations

La Commission a *noté* les points suivants :

- En décembre 2002, l'Assemblée générale des Nations Unies, à sa cinquante-septième session, notant que le riz est l'aliment de base de plus de la moitié de la population mondiale et réaffirmant la nécessité d'appeler l'attention mondiale sur le rôle que peut jouer le riz dans la sécurité alimentaire et la réduction de la pauvreté, a déclaré 2004 Année internationale du riz.
- Le deuxième comité de la soixantième session de l'Assemblée générale des Nations Unies, en novembre 2005, a reconnu le succès de l'Année internationale du riz en 2004, la contribution que son application a apporté à l'amélioration effective de la prise de conscience du rôle joué par le riz pour réduire la faim et la pauvreté ainsi que le soutien de toutes les parties prenantes en vue d'une production rizicole durable.
- Le riz offre aux consommateurs davantage de calories que d'autres aliments de base, notamment dans l'alimentation des couches très pauvres de la population qui consacrent plus de la moitié de leurs revenus à l'achat de leur nourriture. Les femmes et les enfants, en Afrique subsaharienne, en Asie du Sud et du Sud-Est, en Amérique latine et aux Caraïbes sont particulièrement exposés aux carences en micronutriments (surtout en vitamine A, en fer et en zinc).
- Pour la troisième année consécutive, la production mondiale de riz paddy a enregistré une nette expansion en 2005, atteignant le niveau record de 629 millions de tonnes. Cela dit l'accroissement de la production mondiale en 2005-06 permettra à peine de couvrir l'utilisation.
- La production de riz en Afrique subsaharienne est encore insuffisante par rapport à la consommation, alors que l'insécurité alimentaire et la pauvreté sévissent dans les systèmes rizicoles de culture pluviale en Asie où la demande de nourriture a progressé rapidement.
- La population mondiale continue à augmenter rapidement, alors que les ressources en terres et en eaux pour la production rizicole diminuent du fait de la concurrence exercée par d'autres secteurs de l'économie et par l'accroissement de la population mondiale. Qui plus est, l'environnement et les ressources naturelles nécessaires à la production rizicole sont dégradés du fait de la contamination liée aux pesticides et aux fertilisants.
- La hausse des températures et du niveau des mers et les précipitations irrégulières dues aux modifications des conditions climatiques mondiales peuvent se répercuter de manière négative sur la productivité des cultures de riz.
- Des tests pilotes conduits par la FAO, les États Membres et les institutions partenaires ont montré l'efficacité des pratiques de gestion intégrée des cultures rizicoles pour réduire l'écart de rendement (c'est-à-dire la différence entre le rendement potentiel des variétés existantes et les résultats

effectivement obtenus par les agriculteurs), relever les profits des agriculteurs et réduire les dommages à l'environnement.

- Outre la mise au point de variétés à haut rendement, le riz hybride et le riz NERICA sont les deux principaux résultats obtenus dans le domaine de l'amélioration du riz. En 2004, environ 1,5 million d'hectares ont été ensemencés en riz hybride dans divers pays d'Asie, outre environ 15 millions d'hectares en Chine. Dans les pays d'Afrique subsaharienne les agriculteurs sont en train d'adopter le riz NERICA.

Principales recommandations

La Commission a *recommandé* les mesures suivantes:

- Les États membres, les bailleurs de fonds, la FAO, les institutions partenaires et toutes les parties prenantes devraient renforcer les efforts de collaboration et le soutien financier aux activités intéressant la mise en œuvre complète des recommandations en vue d'un accroissement durable de la production rizicole pour réduire la faim et la pauvreté.
- Les partenariats dans le domaine de la recherche rizicole et du développement, entre les institutions nationales et internationales, ainsi qu'entre les ONG (organisations non gouvernementales) et le secteur privé devraient être renforcés et élargis pour une contribution réelle à l'accroissement durable de la production rizicole dans les États Membres.
- Les systèmes de production rizicole devraient être appréhendés de manière globale, de la sélection des semences à la consommation, en tenant compte des interactions et des relations entre les plants de riz et les autres organismes des écosystèmes rizicoles, en vue d'accroître les revenus, d'améliorer la nutrition et de conserver les ressources naturelles nécessaires à la production pour l'avenir.
- Les stratégies et les politiques relatives à la production durable de riz devraient viser à renforcer la capacité des riziculteurs dans la gestion de précision afin d'améliorer l'efficacité de l'utilisation des ressources (surtout l'eau), réduire les dommages à l'environnement et renforcer la compétitivité économique des systèmes de production rizicole. Les directives et les critères de suivi pour la durabilité des systèmes de production rizicole devraient donc être élaborés pour chacune des agroécologies rizicoles en vue de favoriser la formation des agriculteurs.
- Les efforts pour améliorer la nutrition humaine devraient prévoir des initiatives visant à promouvoir le développement, la diffusion et l'adoption de variétés de riz à fort contenu en fer, en zinc et en vitamine A ainsi que renforcer la prise de conscience des consommateurs et obtenir le soutien de l'industrie.
- L'élaboration de variété ne devrait pas seulement tenir compte des rendements, mais aussi de l'accroissement de la valeur nutritionnelle et de la tolérance accrue à la salinité, aux températures élevées, à la sécheresse et aux inondations.
- Les petites et moyennes entreprises qui utilisent les technologies pour transformer le riz entier – y compris le riz usiné, le son de riz et les balles de riz - en produits à valeur ajoutée devraient être encouragées à accroître les revenus dérivés de la production de riz et développer les possibilités d'emploi.
- Le Secrétariat de la Commission devrait organiser une Consultation mondiale d'experts, entre la vingt et unième (2006) et la vingt-deuxième (2010) session, afin d'étudier les progrès accomplis et déterminer les stratégies à adopter pour élargir le transfert de la gestion intégrée des cultures rizicoles, pour combler l'écart de rendement, augmenter les profits et réduire la dégradation de l'environnement dans les systèmes rizicoles importants.

Date et lieu de la prochaine session

La Commission a exprimé son appréciation pour l'invitation faite par la délégation française d'accueillir la vingt-deuxième session en 2010. La décision finale relative à la date exacte et au lieu précis sera prise par le Directeur général de la FAO en consultation avec le gouvernement de l'État membre concerné.

Resumen del informe de la 21ª reunión de la Comisión Internacional del Arroz

La Conferencia de la FAO, en su cuarto período de sesiones celebrado en 1948, estableció la Comisión Internacional del Arroz (CIA) con el objetivo de fomentar la adopción de medidas nacionales e internacionales relativas a la producción, conservación, distribución y consumo de arroz. La Constitución de la Comisión entró en vigor en 1949. El número de sus Estados Miembros se ha elevado de 15 en 1949 a 61 en la actualidad. Cada cuatro años la CIA organiza una reunión con objeto de examinar los nuevos problemas y los progresos recientes en ámbitos científicos, técnicos y socioeconómicos relacionados con la producción arrocera sostenible y los sistemas agrícolas basados en el arroz. Además, ayuda a los Estados Miembros a orientar sus estrategias para llevar adelante sus programas nacionales de fomento del arroz, a la vez que impulsa una amplia interacción entre las instituciones nacionales, regionales e internacionales.

La 20ª reunión de la CIA se celebró en Bangkok (Tailandia) en el año 2002. El Ministerio de Agricultura del Perú y la FAO convocaron la 21ª reunión de la CIA, que tuvo lugar en el Hotel Gran Chiclayo, en Chiclayo (Perú), del 3 al 5 de mayo de 2006. El tema principal fue "El arroz es vida: Llevar la aplicación del AIA a los campos de los agricultores". Asistieron 90 delegados y participantes de Estados Miembros e instituciones colaboradoras. Hubo cinco subsesiones, una exposición visual y una visita de campo.

Observaciones principales

La Comisión *señaló* lo siguiente:

- En diciembre de 2002, la Asamblea General de las Naciones Unidas en su 57º período de sesiones, observando que el arroz es el alimento básico de más de la mitad de la población del mundo y reafirmando la necesidad de concentrar la atención mundial en la función que puede desempeñar el arroz en la consecución de la seguridad alimentaria y la erradicación de la pobreza, proclamó el año 2004 Año Internacional del Arroz.
- El Segundo Comité del 60º período de sesiones de la Asamblea General de las Naciones Unidas, celebrado en noviembre de 2005, reconoció los buenos resultados de la observancia del Año Internacional del Arroz en 2004 y su contribución a la sensibilización sobre la función que desempeña el arroz en la reducción del hambre y la pobreza, así como el apoyo de todas las partes interesadas a la producción sostenible del arroz.
- El arroz aporta a los consumidores más calorías que otros productos básicos, sobre todo en la alimentación de las personas muy pobres, para las cuales la compra de alimentos constituye más de la mitad del total de los gastos. Las mujeres y niños del África subsahariana, el sur y sudeste de Asia, y América Latina y el Caribe son especialmente susceptibles a las deficiencias de micronutrientes, sobre todo vitamina A, hierro y cinc.
- Por tercer año consecutivo, la producción mundial de arroz registró un fuerte crecimiento en 2005, lo que elevó la producción total hasta un nivel sin precedentes correspondiente a 629 millones de toneladas. Sin embargo, el incremento de la producción mundial en 2005-06 sólo alcanzará para cubrir la utilización.
- La producción de arroz en el África subsahariana sigue viéndose superada por el consumo, en tanto que la inseguridad alimentaria y la pobreza se generalizan en los ecosistemas de arroz de secano en Asia, donde la demanda de alimentos ha estado creciendo con rapidez.
- La población mundial sigue aumentando de manera constante, mientras que los recursos de tierras y aguas para la producción de arroz disminuyen debido a la competencia de otros sectores de la economía y al aumento de la población. Además, el medio ambiente y las bases de recursos naturales para la producción de arroz están deteriorándose a causa de la contaminación por plaguicidas y nutrientes.
- El aumento de las temperaturas, la subida del nivel del mar y la distribución de lluvias irregulares a tenor del cambio climático mundial podrían tener amplias repercusiones negativas en la productividad del cultivo de arroz.
- Ensayos experimentales realizados por la FAO, Estados Miembros e instituciones colaboradoras han demostrado la eficacia de los

sistemas de gestión integrada de los cultivos del arroz para cerrar la brecha de rendimientos de este cultivo (esto es, la diferencia entre el rendimiento potencial de las variedades actuales y los rendimientos que obtienen realmente los agricultores), aumentar los beneficios de los agricultores y reducir al mínimo los daños causados al medio ambiente.
- Tras obtener variedades de alto rendimiento, el arroz híbrido y el arroz NERICA constituyen los dos logros principales en el campo del mejoramiento del arroz. En 2004, se plantaron en torno a 1,5 millones de hectáreas de arroz híbrido en varios países asiáticos, además de los casi 15 millones de hectáreas plantadas en China. En el África subsahariana, los agricultores están adoptando la variedad de arroz NERICA.

Recomendaciones principales

La Comisión *recomendó* lo siguiente:
- Los Estados Miembros, donantes fundadores, la FAO, instituciones colaboradoras y todas las partes interesadas deberían aumentar su colaboración y apoyo financiero a actividades encaminadas a lograr la plena aplicación de las recomendaciones de la Comisión para aumentar de forma sostenible la producción de arroz a fin de reducir el hambre y la pobreza.
- Debería reforzarse y ampliarse la colaboración en la investigación y fomento del arroz entre instituciones nacionales e internacionales, así como ONG (organizaciones no gubernamentales) y el sector privado, para contribuir eficazmente a incrementar de manera sostenible la producción del arroz en los Estados Miembros.
- Los sistemas de producción del arroz deberían contemplarse de forma integrada, desde la selección de semillas hasta los alimentos en la mesa, teniendo en cuenta la interacción y las asociaciones entre las plantas de arroz y otros organismos de los ecosistemas arroceros, a fin de elevar al máximo los ingresos y la mejora de la nutrición y conservar los recursos naturales para la producción futura.
- Las estrategias y políticas relativas a la producción sostenible del arroz deberían procurar fortalecer la capacidad de los agricultores de arroz en la agricultura de precisión a fin de: mejorar la eficiencia de la utilización de recursos (en especial el agua), reducir los daños ambientales y favorecer la competitividad económica de los sistemas de producción del arroz. Por consiguiente, deberían elaborarse directrices y criterios para llevar a cabo un seguimiento de la sostenibilidad de los sistemas de producción del arroz para los distintos contextos agroecológicos de este producto a fin de posibilitar la capacitación de los agricultores.
- Entre las actividades para mejorar la nutrición humana deberían figurar iniciativas destinadas a: promover la obtención, distribución y adopción de variedades de arroz con un contenido elevado de hierro, cinc y vitamina A, sensibilizar a los consumidores y obtener el apoyo de la industria.
- La obtención de variedades debería centrarse no sólo en las variedades de alto rendimiento sino también en variedades con un valor nutritivo más elevado y una mayor tolerancia a la salinidad, las elevadas temperaturas, la sequía y el estrés por inundaciones.
- Deberían fomentarse las pequeñas y medianas empresas que emplean tecnologías para transformar el grano entero de arroz (incluido el arroz elaborado, el salvado de arroz y las cascarillas de arroz) en productos de valor añadido con objeto de aumentar la rentabilidad obtenida de la producción de arroz y crear oportunidades de empleo.
- La Secretaría de la Comisión debería organizar una consulta de expertos mundial, entre la 21ª reunión (2006) y la 22ª reunión (2010), en la que se examinarán los progresos realizados y se identificarán las estrategias convenientes para mejorar la transferencia de sistemas de gestión integrada de cultivos del arroz a fin de cerrar la brecha de rendimientos, aumentar los beneficios y reducir el deterioro ambiental en los sistemas importantes de producción basados en el arroz.

Fecha y lugar de la próxima reunión

La Comisión manifestó su agradecimiento por la invitación de la delegación de Francia para albergar la 22ª reunión, que tendrá lugar en el año 2010. El Director General de la FAO, en consulta con el gobierno del Estado Miembro en cuestión, tomará la decisión final sobre la fecha y el lugar exactos de celebración.

African smallholder farmers: rice production and sustainable livelihoods

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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

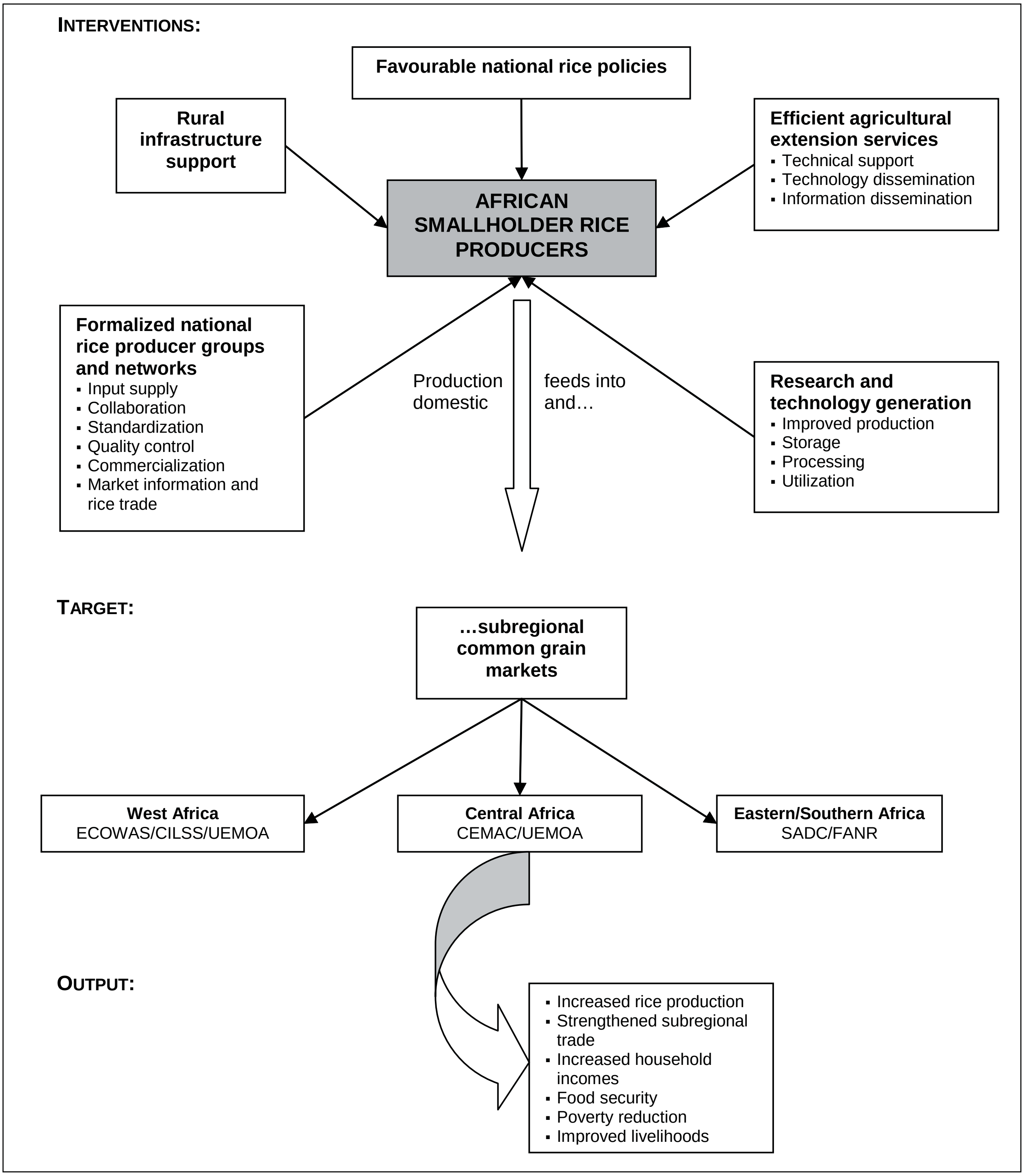
Rice forms the basis of the diet of millions of people in SSA. Starch from broken rice is used as laundry starch and has wide industrial applications. By-products, such as rice bran, rice hulls and rice straw, also have several uses.

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

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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).

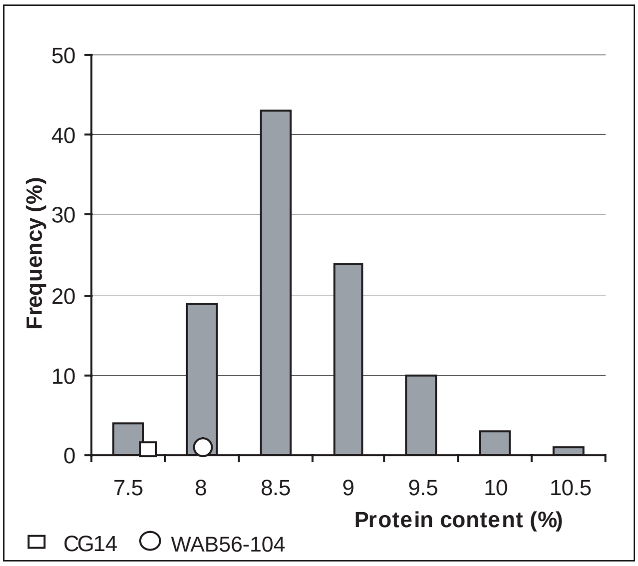
These results show that some of the weed competitiveness characteristics of the *O. glaberrima* parent were actually inherited by some of the NERICA lines, but no combination of competitive traits was found in one single NERICA, confirming earlier studies by Dingkuhn *et al*. (1998, 1999). They showed 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 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.

FIGURE 1
Frequency distribution of protein content



Source: WARDA, 2005a.

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

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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.

Rice production in Latin America at critical crossroads

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RICE TRENDS IN LAC

In the twentieth century, per caput rice consumption in Latin America and the Caribbean (LAC) increased from 10 to 30 kg. Rice now supplies more calories to the diet than wheat, maize, cassava or potatoes and it is especially important in the diets of the poor. Rice is a versatile crop, and it is grown in a wide range of climates, soils and moisture conditions. About 55 percent of the crop (3.6 million ha) is grown with irrigation or in wetlands. About 45 percent (3.0 million ha) is grown under rainfed conditions.

Twenty-six countries in the LAC region grow rice, and annual production in 2004 was estimated at 25.8 million tonnes of paddy. This means that LAC accounts for about 4.2 percent of world rice production (estimated at 605 million tonnes of paddy), increasing from the average production in 2002-03 of 22 million tonnes. During this period, yields saw an increase from an average of 3.5 to over 4.0 tonnes/ha, while the area under production decreased, mainly as a result of the low world prices. In 2004, as prices recovered, the area under production increased to the same area as in 2000. This is indication that rice production in LAC is sensitive to world rice prices.

The semitropical or temperate zones of southern Brazil, Uruguay and Argentina are dominated by irrigated rice and they are net exporters. This is in contrast with Central America and Mexico, where rice is grown in both irrigated and upland conditions and rice production is less than half the level of rice consumption. In southern Brazil and Uruguay, both the public and private sectors have strong rice programmes. In the smaller countries of Central America, on the other hand, the national programmes tend to involve few people in rice research and the private sector is often dominated by smaller regional companies.

CURRENT POLICIES OF NATIONAL GOVERNMENTS TO SUPPORT RICE PRODUCTION

NAFTA and its effect on rice production in Mexico

The United States accounts for approximately 12 percent of global rice exports. The largest market for United States rice is Latin America. Mexico is part of the North American Free Trade Agreement (NAFTA) that came into effect in 1994. Although the first few years were difficult and there was a severe devaluation of the currency in 1994, Mexico has gained many benefits from NAFTA and per caput income has doubled in the last decade. The rice sector in Mexico has not been so fortunate. While the United States spends over US$1 billion a year to subsidize rice, the Mexican Government has done little to support rice production in Mexico.

Under the agreement, the United States phased out its tariffs on rice imports from Mexico over a 10-year period. Mexico also phased out its tariffs (10 percent for United States paddy rice and 20 percent for United States refined rice) over a 10-year period. No quantitative restrictions affect United States and Mexican trade in rice.

The effect of the agreement has been an increase in rice imports to Mexico from the United States. This increase was affected by world rice prices and subsidies to United States farmers. As rice became cheaper, it was hard for the Mexican farmers to compete, and imports began to increase sharply in 1999. There is high demand among Mexican consumers for a short-grain rice that is not commonly produced in the United States; this demand prevented the reduction in production from being even greater.

The Mexican rice sector is becoming more organized, and the Consejo Mexicano del Arroz is promoting both rice production and consumption, with financial assistance from the Mexican Government. In 2004, it became a member of FLAR (Latin American Fund for

Irrigated Rice) with the aim of increasing activities in rice breeding and crop management. Yields in Mexico average slightly over 4 tonnes/ha and the rice sector must increase yields significantly and reduce production costs if it is to become competitive in an arena without protection.

CAFTA and its effect on the rice sector

The United States, El Salvador, Guatemala, Honduras and Nicaragua have ratified the CAFTA (Central American Trade Agreement) treaty. Ratification of the treaty by Costa Rica is pending, and Panama is not included in the treaty. Central American countries are the second largest importer of rice from the United States, importing a combined total of about 550 000 tonnes per year. The CAFTA treaty imposes a complex mixture of tariff rate quotas (TRQs). During the first year of CAFTA, the TRQs are 343 000 tonnes of paddy and 44 000 tonnes of milled rice. Paddy rice will be charged a tariff of 5 percent and milled rice a tariff of 10 percent. Any additional imported rice will be charged tariffs ranging from 20 to 35 percent on paddy rice and from 30 to 45 percent on milled rice, depending on the importing country. The quantity of rice imported under the quota will increase by 5 percent a year for milled rice, and by 2 percent a year in Costa Rica, El Salvador and Honduras, 3 percent in Nicaragua, and 5 percent in Guatemala. Duties on all types of rice will be phased out over the next 18 to 20 years. The reduction in quotas applies only to the CAFTA countries, and they are expected to manage the TRQs in a manner that encourages the quotas to be filled.

The only country that agreed to a quota higher than current imports is Guatemala. Per caput consumption in Guatemala is only 8 kg per person. This means that local producers will begin competing directly with United States rice in the first year of the CAFTA treaty. The Guatemalan Rice Association (ARROZGUA) promotes both rice consumption and production. Central American countries only produce about half of the rice they consume; most of the remainder is imported from the United States. Therefore, the other countries have time to increase the efficiency of their rice production before having to compete directly with imported rice. As for Mexico, meeting this challenge will require better organization both in the development of new varieties and in the management of the crop. As the rice sector employs 1.2 million people, it must become competitive and contribute to lowering the rates of poverty in this region.

POTENTIAL FOR RICE PRODUCTION

Rice is a crop that depends on water and most rice production depends on irrigation. Latin America is a region that still has ample water and land; the only other continent with a comparable abundance of water is North America. In contrast, water is a relatively scarce resource for Asia, Africa and Europe.

Given the consistent rainfall in many regions, about 40 percent of rice production in Latin America is upland or non-irrigated rice. Although yields tend to be lower, it is economical to produce upland rice because the cost of production is significantly less than the cost associated with irrigated production. There are major areas of upland rice in Brazil and Bolivia.

Rice production is very dependent on water and the most consistent and highest yields occur in irrigated systems. Most irrigated rice is in flooded fields. However, it is easier to control weeds, pests and diseases if irrigation can take place during the drier times of the year. In the desert coastal areas of Peru, rice is irrigated by mountain water and yields are often above 12 tonnes/ha. There are many areas of Latin America that can potentially produce large quantities of rice, but they lack the infrastructure to do so.

For rice production to substantially increase, it must be able to compete in the export market. Given the estimated US$25 billion of subsidies for United States rice production, it is difficult for LAC to compete. Nevertheless countries like Uruguay are competing and exporting most of the rice that they produce. Latin American rice producers need to support the development of modern varieties with multiple stress resistance, adopt effective integrated crop management strategies, and develop post-harvest processing systems that will help to stabilize the local rice prices. Latin America has the potential to fill the increasing demand for rice that is occurring with the increase in population.

In most LAC countries, the internal price of rice is higher than the border price for imported rice. While subsidies play a role in this discrepancy, it is also the result of a combination of high costs and low yields, which result in relatively high unit costs for rice. As a rule of thumb, countries should have a target of US$1 000 per hectare costs, with yields of at least 7 tonnes/ha to be able to supply rice at a competitive price. While this is feasible, it is not the norm. In the temperate regions, these targets have been reached by many farmers. Rice-pasture rotation helps on both fronts: lower costs and higher yields. In the tropics, low luminosity during the rainy season becomes a hindrance for low cost and high yield. To move away from that condition, water harvesting programmes will have to be implemented to allow farmers to produce in the dry season, with high luminosity and favourable conditions for pest and disease control.

RICE BREEDING PROGRAMMES

Rice production has been quite dynamic in this region. Following the late 1960s, over 300 new varieties were released and production tripled with 80 percent of this increase due to higher yields. The main beneficiaries of the process are consumers, as real rice prices dropped by over 40 percent in the same period (Sanint, 1992).

Conventional rice breeding

Rice programmes vary – from well-financed multi-disciplinary teams to poorly funded groups with activities in rice breeding. They include national programmes, state programmes, and programmes run by rice federations, universities and private companies. The capacity ranges from developing and testing crosses, to simply evaluating a limited number of fixed lines. To be effective, smaller programmes must be associated with organizations that develop fixed lines. Two such organizations, the FLAR and GRUMEGA (Working Group on Advanced Rice Breeding) networks, currently support activities in irrigated and upland rice. Rice programmes in both the public and the private sector are facing more open markets; they are collaborating more closely and understand the need for this trend to continue. The International Network for Genetic Evaluation of Rice (INGER) in LAC has been relatively inactive during the last few years. CIAT, FLAR and IRRI understand that there is an urgent need to revitalize this mechanism for germplasm evaluation and distribution. Some of the major activities and trends in rice breeding for LAC are described below.

FLAR breeding activities

FLAR was created in 1995 in response to decreasing budgets at CIAT for rice research. Its main focus was to maintain the flow of elite lines to and from the region and the generation of new lines with enhanced characteristics that are the basis for the efficiency and competitiveness of the sector. FLAR currently has 14 member countries, i.e. the majority of countries with an important rice sector.

The FLAR breeding programme is mainly a varietal development effort shared by its members to achieve economies of scale and avoid duplication of efforts in a carefully crafted process that takes advantage of the division and specialization of labour. The programme has two main domains in terms of the varieties being developed: temperate and tropical. FLAR delivers segregating lines to its partners, which, in turn, finish the selection process to identify those that are released as new varieties. Representatives in each member country are responsible for the protection of the varieties and for collecting fees to keep the model financially healthy and operational.

Recurrent selection

Population breeding by recurrent selection is efficient for trait improvement showing low heritability. Through short cycles of selection and recombination, linkage blocks are broken down and favourable genes are accumulated. This is a smooth process of continuous improvement. The methodology applied to rice and implemented by the project was described in a handbook by Châtel and Guimarães (1998).

Basic composite populations are enhanced using two recurrent selection-breeding methods: mass and S_2 progenies evaluation. At each step of enhancement, fertile plants are selected for the development of segregating lines and progeny selection using the conventional pedigree method. One major advantage of this method is that populations are started with many parents, and more than 20 parents are often used to develop the basic composite populations. These populations can target specific ecosystems or complex traits, such as drought tolerance, through the selection of the founding parents.

The CIRAD (International Cooperation Centre of Agricultural Research for Development)/CIAT rice collaborative project concentrates on broadening the genetic base of rice through composite population improvement using the recurrent selection method combined with conventional breeding methods. Guimarães (2005) documents many of the advances that have been made using recurrent selection in rice breeding throughout LAC.

Both populations and advanced upland lines are locally screened and selected. The most promising lines are evaluated at regional yield trials. In Chile, the population-breeding project uses site-specific populations developed from the introgression of local adapted material into the population GPIRAT-10. The Chilean populations are enhanced for cold tolerance and other agronomic traits. During the enhancement process, segregating lines are developed and advanced lines are already in yield trials. A promising line could be released next year if its behaviour is confirmed. In Venezuela (Bolivarian Republic of), in the Fundación DANAC rice breeding project, 43 percent of the advanced lines come from selections made in different introduced and site-specific composite populations, and a line from the population PCT-16 was identified as a candidate cultivar for launching as a commercial variety in 2007. In Argentina, the population-breeding project was started in late 1996 with the introduction of populations from Colombia. From the best-adapted germplasm (PCT-8), a site-specific population was set up (PARG-3) and characterized for different traits. About 150 breeding lines are in the pipeline for fixed line development.

The first irrigated variety in LAC that was developed using recurrent selection was released by EPAGRI (Empresa Catarinense de Pesquisa Agropecuária), Santa Catarina, Brazil in 2003, and it was named in honour of the retiring rice breeder, Tio Taka. The first upland variety selected from the composite population PCT-4 was officially launched as a variety in January 2006. The variety is adapted to upland traditional and mechanized rice systems. For small farmers, the advantages of this variety include earliness and drought tolerance, as well as good yield potential. Earliness is a very important trait, because farmers can put rice on the market early in the season and get good prices. It also gives farmers time to plant a second higher value crop which is important for income generation.

Recurrent selection helps increase variety diversity and also the probability of selecting for complex traits such as drought stress. As with all breeding activities, a long time is required. Only after 10 years of using this method are varieties starting to be released. There are more than ten breeding programmes that use recurrent selection and they are associated in GRUMEGA. This network helps build regional relations between breeding programmes through LAC, and conducts workshops where advanced materials are available for selection. These workshops are important for the larger breeding programmes and essential for the smaller ones. They have also been an effective forum for promoting the innovative breeding method of recurrent selection.

MINING THE WILD RICE SPECIES

The genus *Oryza* consists of 21 wild rice and two cultivated species. After 6 000 years of continuous selection by man and intensive breeding efforts during the last 100 years, the genetic base of the crop is narrower than ever. The modern high-yielding rice varieties that ushered in the Green Revolution brought about dramatic increases in rice production worldwide, but a narrower genetic base. The *Oryza* wild species represent a potential source of new alleles for improving the yield, quality and stress resistance of cultivated rice.

The wild relatives of rice are resistant to many pests and diseases for which there is not sufficient genetic resistance in rice. There are even components in the wild species that can increase the yield potential of rice. Advanced lines from the cross Lemont/*O. barthii* mature early with good yields and excellent grain quality. Interspecific crosses are being made for many traits, including *O. rufipogon* as a source aluminium tolerance and vigorous root growth. High levels of resistance to the rice stripe necrosis virus were found in *O. glaberrima*, and this resistance has been transferred through interspecific crosses to Bg90-2 and Caiapo. The results for disease resistance are also impressive. Using high disease pressure, advanced breeding lines with resistance to *Rhizoctonia solani* were derived from the interspecific crosses of Oryzica3/*O. rufipogon*.

The diversity of the parents makes these interspecific crosses ideal in studies to develop molecular markers. By using a set of chromosome introgressed substition lines (CISL), the genomic region of the interspecific species can rapidly be identified. Already, they have been used to mark regions of the chromosome of *O. glaberrima* for important traits. Varieties with more diversity, that yield well in environments with low inputs, use water more efficiently and are more nutritious, will be easier to develop if the genetics and molecular basis for these traits are understood.

The future for marker-assisted selection

The entire genome of rice has been sequenced and this has allowed the identification of thousands of DNA markers that are simple-sequence repeat (SSR), best known as microsatellite markers. Since the introduction of the modern high-yielding varieties, many breeding programmes use a genetically narrow gene pool, and marker-assisted selection (MAS) is amenable to high-throughput analysis, and sufficient polymorphism can be found for the parents of most crosses (McCouch *et al.*, 1997).

To increase the efficiency of developing hybrid rice, IRRI uses DNA MAS for the WA cytoplasm restoration ability and thermosensitive genetic male sterility. Markers for quality traits were developed at Texas A&M. Many disease markers are available, including markers for both major and minor resistance genes for rice blast, for rice bacterial blight (*Xanthamonas oryzae*) and planthopper resistance. Rice hoja blanca virus (RHBV) is an important disease in LAC and is costly to screen in the field. One potential marker has already been identified for resistance to this disease.

There are SSR markers available for many other traits, and there are many research programmes working to discover the function of rice genes. At the Fifth International Rice Genetic Congress, it was proposed that the function of all the rice genes should be determined by 2015, and some indicated that it might be possible to achieve this goal as early as 2010. This type of information will allow the widespread development of single nucleotide polymorphisms (SNPs, pronounced "snips") – highly specific markers that are amenable to very high-throughput analysis.

The MAS technologies are being used at a few advanced laboratories, but are still not widely used. As more information is obtained on resistance to biotic and abiotic stresses as well as important agronomic characteristics, the use of MAS will become more compelling. The question is not will MAS become an important standard activity in rice breeding programmes, but when will it be economical to start using this technology?

Potential of transgenic rice

While there are no transgenic rice varieties grown commercially, there are many field experiments throughout the world. Herbicide resistance and stem borer resistance (Bt) is widely deployed in commercial cotton, maize and soybeans. Herbicide resistance would be effective for controlling red rice which is a major problem throughout LAC. Herbicide-resistant rice has been developed but is not available in commercial varieties.

RHBV is a major viral disease of economic importance affecting rice in northern South America, Central America and the Caribbean. Transgenic plants with the RHBV nucleoprotein viral gene are available and were crossed with the commercial variety, Fedearroz 50 (Lentini *et al.*, 2003). Field evaluations indicated that six fixed transgenic lines were more resistant than Fedearroz 2000, the most RHBV-resistant commercial variety. The transgenic lines express low levels of RNA, detectable only by RT-PCR, and the RHBV nucleoprotein is not expressed in these plants, thus suggesting a very low risk, if any, for environmental and food safety concerns.

Rice does not normally produce vitamin A and "Golden Rice" was developed to alleviate vitamin-A deficiency. It was made by inserting two daffodil genes and one bacterial gene into the rice genome. This allows the production of beta-carotene in rice grain. The resulting plants are normal, except that their grain is a golden yellow colour, due to the presence of provitamin A (Ye *et al.*, 2000).

One reason that transgenic rice has not been commercialized is that there are several biosafety issues. One of these issues is the gene flow from rice to red rice. In contrast to temperate regions, where weedy rice is mainly composed of *Oryza sativa f. spontanea* (red rice), in tropical America, the weedy rice complex is diverse and composed of numerous *Oryza* species. The preliminary results demonstrate that there is a natural gene flow rate from transgenic/non-transgenic rice to weedy rice of between 0.0 and 0.3 percent in the field, but no differences were found in the hybridization rates between weedy rice and transgenic or non-transgenic rice. If herbicide resistance is the transgenic trait, there should be few red rice in the field and outcross should be a rare event. However, if transgenic rice becomes commercialized, the post-harvest management of the field will be important for reducing the transfer of transgenic characteristics to weed populations.

The principal reason for which transgenic rice has not been commercialized is related to the politics of transgenic crops. The United States does not wish to jeopardize the European or Japanese export markets, and other countries are also hesitant to be the first to deploy transgenic rice. It is expected that China will be the first country to actually deploy commercial transgenic rice. Given the acceptance of transgenic soybean, maize and cotton in several LAC countries, and taking into consideration the limited amounts of exports, the release of commercial transgenic rice could bring benefits to several countries in the region.

INCREASING PRODUCTIVITY THROUGH INTEGRATED CROP MANAGEMENT

Most countries in LAC do not reach the yield potential of their germplasm, mainly as a result of deficiencies in crop management. Most countries are now quite active in terms of identifying constraints and tackling them jointly – FLAR has focused on agronomy in the past 5 years, thanks to a project supported by FAO and the Common Fund for Commodities (CFC). CIAT also accompanies these regional efforts.

Integrated production and pest management

There are several proposed systems of integrated production and pest management (IPPM). They are all knowledge intensive and depend on the development of a set of best management practices. An example of IPPM is the RiceCheck system – described in detail by Clampett, Nguyen and Tran (2003). Another example is the Management Program for the High Production of Rice, described by Dr Edward Pulver during this IRC meeting.

IPPM systems involve proper fertilization, water and weed management, timing and density of planting, monitoring for pests and diseases, and the judicious use of inputs. These practices are based on a knowledge-based system with intensive management. It is important to know the principal varieties and their behaviour within the context of the local agro-ecosystem. Proper crop management is essential if Latin America's rice farmers wish to be competitive.

PRINCIPAL PEST PROBLEMS IN LATIN AMERICA

The mite complex: a new challenge

During the mid-1990s, a new pest complex caused economic damage in Cuba. There were severe outbreaks of *Sadocladium*, which is normally a minor problem. There were also an unusually high number of sterile spikes. The mite *Stenopheles spinki* – principally a pest in Asia – was found in high numbers in the affected field. It was also found in Haiti and the Dominican Republic. For the following decade, this pest was thought to be localized in these islands. The Cuban rice research programme developed mutants of a couple of popular varieties and started selection of new varieties with resistance to the mite.

In 2004, there was a major outbreak of grain discolourization. This was discovered to be a complex between *S. spinki* and bacteria. Higher levels of *Sadocladium* were also reported in some areas. Countries started monitoring activities for *S. spinki* which was found in Nicaragua, Panama and Colombia. In Panama, it is associated with outbreaks of bacteria. In Colombia, the region of Casanare had multiple disease problems and it is suspected that *S. spinki* was part of the complex.

Varietal resistance exists for this mite and many commercial varieties have been classified as susceptible or tolerant. Tolerance to *S. spinki* is to be added as one of the breeding goals in many of the breeding programmes in the affected region.

Crop management is the most important way to control the pest and disease complex associated with *S. spinki*. Farmers need to resist indiscriminate spraying for the mite. The insecticides that are effective also eliminate the beneficial spiders that are biological control agents for the rice crop. Before any application of pesticides, one needs to monitor the field and determine the level of infestation. Given that *S. spinki* colonizes the interior of the leaf sheath, monitoring is not as easy as for other insects. Protocols for determining the level of infestation were developed and are available on several Web sites and in pamphlets. The best management practices in IPPM tend to produce rice plants that are hardier. These plants are also more resistant to damage from *S. spinki*. These management practices also encourage the build-up of natural enemies of the mite. In areas where the mite is a problem, a variety that is moderately tolerant to the mite should be selected and IPPM should be used.

Rice blast: a continuing challenge

Most commercial varieties remain resistant to rice blast (*Mangaphora gresia*) for only 1 to 3 years. There is a tug of war between the pathogen and the host. While a host may be resistant to many of the rice blast isolates, there always seems to be a subset of the population that is not recognized by the plant's defences and it soon becomes predominant. The resistance is then broken and the new variety becomes susceptible to rice blast. Hot spot selection under high disease pressure and pathogen diversity has been the principal method for breeding rice-blast-resistant lines and varieties. For example, the variety, Fedearroz 50, is widely grown in Colombia and has remained highly resistant to rice blast since its introduction in 1998. This contrasts with most new varieties that start to have problems 1 to 2 years after release.

Much work remains before it can be declared that there are the knowledge and methods to consistently develop rice with durable resistance, but there is evidence that, step-by-step, progress is being made. Oryzica Llanos 5 is a variety that was developed through hot spot breeding; it is exceptional because it has remained resistant to rice blast for more than 15 years. The genome of Oryzica Llanos 5 is being analysed and contains several major resistance genes as well as a group of minor resistance genes.

This is part of a greater effort to catalogue both the resistance genes in the plant and the virulence genes in the fungus. The fungal isolates can be characterized using near isogenic lines carrying individual resistant genes. This can identify the most common rice blast linages in an area. On the plant side, the rate of discovery of rice blast resistance gene is one of the benefits of knowing the entire rice genome sequence. Testing of resistant gene combinations that confer durable resistance is being done and this knowledge leads to designer varieties with better resistance to rice blast.

Rice hoja blanca virus

Since the mid-1950s, the development of rice varieties with resistance to rice hoja blanca virus (RHBV) has been a breeding objective. The virus is transmitted by the planthopper *Tagasodes orizicolus*. For many years, only one source of resistance was widely used in breeding programmes, and there was only marginal progress. Most commercial varieties are still not resistant to hoja blanca disease. In the mid-1990s, when it appeared that a new epidemic was imminent, CIAT – with the collaboration of FEDARROZ in Colombia and DANAC in Venezuela (Bolivarian Republic of) – started working intensively on developing resistant varieties. In addition to the mass screen method that has been in place since the mid-1980s, an evaluation scheme using different levels and timing of disease pressure in randomized block design was introduced. These efforts led to the development of five varieties with resistance to hoja blanca disease. Two varieties, Fedearroz 2000 and Fedearroz Victoria 1, have resistance that is superior to any of their parents. Because most breeding programmes do not have capacity to screen for RHBV, most commercial varieties are not resistant to RHBV.

Progress is being made in understanding the genetics and in developing markers for resistance to both the virus and its vector. There are more breeding programmes which have access to laboratories with the capability to implement MAS than to viruliferous colonies of *T. orizicolus*. This use of MAS for RHBV should lead to the development of more commercial varieties with resistance to this disease.

Reaching the small rice farmers

One of the most innovative activities in terms of meeting the needs of small rice farmers is the CIRAD/CIAT rice participatory breeding project. Since 2003, upland composite populations and advanced and segregating lines developed by CIRAD/CIAT have been evaluated in Nicaragua. While some of the evaluation has been done in a traditional manner with the National Agricultural Research Institute, many of the materials were evaluated using participatory variety selection (PVS). Composite populations are also being evaluated using participatory plant breeding (PPB). The organization of the groups, the involvement of the farmers, the exchange of local and technical information are all important benefits of this method. By having more access to information and the ability to function as a group, the small farmers are empowered to develop solutions to their critical needs. Activities focus on selecting rice varieties adapted to the needs of the small farmer; the outcome is social benefits to the small farmers and their communities.

CONCLUSIONS

About 4.2 percent of total global rice production is harvested in Latin America and the Caribbean and this percentage has been increasing in recent years. Net consumption is nearly equal to production with the southern cone countries, where a surplus is produced; Central America, Mexico and the Caribbean region are net importers. Both the major exporters of the southern cone and the net importers of Central America and the Caribbean are facing a similar challenge. In order to increase production, their rice farmers must produce rice that competes with rice in the export markets.

In order to effectively compete, rice yields must continue to increase while the costs associated with production are reduced. The new varieties must be of excellent grain quality, have multiple stress resistances and high yield potential. Yield potentials needs to be exploited by making investments in the land and water resources. Good agronomic practices include: effective fertilization; water and weed management; lower plant densities; and growing rice during the seasons of highest solar radiation.

Both government and the private sector must be committed to:

- supporting the development of varieties;
- creating access to certified seed, extension and other information services; and
- providing a system of credit and crop insurance.

The universities – which are very important in the United States for both research and extension activities – are very limited in LAC. This type of support is not a subsidy and the countries of LAC need to increase their investments in these institutions for the whole agricultural sector.

Finally, as long as the rice sector in LAC remains divided and continues to compete with other national organizations, the sector remains in jeopardy. The different actors need to work together to influence government policy and strengthen investment in rice farming. Availability of water, land and human resources is not a problem. With the new trade agreements and the region reaching self-sufficiency in rice production, LAC is at a crossroads. Will there be enough unity in the rice sector to influence policy and attract local investment or will it remain a sector with many small and somewhat conflicting voices that lacks the clout to influence governments or attract investment from the private sector. Organizations, such as FLAR and FEDARROZ, are a sign that the rice sector understands the challenge and wants to develop strategies to become more productive. To achieve this, governments and the private sector need to help strengthen the public sector, including the international centres, national and state programmes, and universities. The rice sector may then continue to evolve and prosper.

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La production de riz en Amérique latine: une étape décisive

Relativement bon marché, le riz est devenu un bien de consommation courante en Amérique latine et dans les Caraïbes. Il occupe une place toute particulière dans l'alimentation des pauvres. Alors que la production et la consommation de riz sont en équilibre si l'on considère l'ensemble de la région, on relève un déficit en Amérique centrale et dans les Caraïbes et un excédent dans le cône austral.

Les accords de libre-échange ont actuellement des répercussions négatives sur la production au Mexique et affecteront bientôt la production en Amérique centrale. La production du cône austral doit être rentable pour permettre la compétitivité sur le marché international du riz. La solution a consisté à augmenter le soutien aux riziculteurs ce qui a permis d'accroître les rendements au cours des cinq dernières années. Si cette tendance se confirme, des progrès devront être accomplis dans le développement des variétés et la gestion des cultures.

Le présent article décrit l'orientation actuelle, le potentiel de production du riz et certaines des activités axées sur l'augmentation de la compétitivité de la culture du riz en Amérique latine et dans les Caraïbes.

La producción de arroz en América Latina en una difícil situación

Dado que el arroz es relativamente barato, se ha convertido en uno de los alimentos básicos principales de América Latina y el Caribe, con especial importancia en la alimentación de las personas pobres. Aunque la producción y el consumo de arroz en la región muestran en general un equilibrio, la región de América Central y el Caribe presenta un déficit frente al superávit que se registra en la región del Cono Sur.

Los acuerdos de libre comercio están afectando de forma negativa a la producción en México y pronto comenzarán a afectar a la producción de América Central. El Cono Sur tiene que resultar rentable para que los productores compitan en los mercados de arroz internacionales. La reacción ha sido aumentar el apoyo a los cultivadores de arroz, y en los últimos 5 años los rendimientos se han incrementado considerablemente. Si se mantiene esta tendencia, será necesario realizar nuevos avances tanto en la obtención de variedades como en la gestión de cultivos.

En este artículo se describen las tendencias actuales, el potencial de producción de arroz y algunas de las actividades que pretenden aumentar la competitividad del cultivo de arroz en América Latina y el Caribe.

Challenges and opportunities for sustainable increase of rice production in the Near East region

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Rice is the third largest crop in the Near East region in terms of area sown after wheat and cotton; Egypt, Pakistan, Iran (Islamic Republic of), Morocco, Iraq, Turkey, Mauritania and Sudan are the main producing countries. Rice occupies about 3.9 million ha annually, playing a significant role in the strategy to overcome food shortages. Total production is about 17.9 million tonnes with an average productivity of 4.6 tonnes/ha. With the exception of Egypt and Pakistan, which had an exportable surplus in 2004 of about 1.0 and 1.8 million tonnes, respectively, the countries in the region are net rice importers. It is estimated that approximately half of the rice consumed in Near East countries is imported every year (FAO, 2003). In 2004, the total amount of milled rice exported from rice-producing countries in the Near East region was only 2.8 million tonnes, while the imported amounts were about 1.1 million tonnes.

The irrigated agro-ecology is the most favourable for very high yields. However, high variability in rice yield exists among the countries in the region. The average national yield is 9.83 tonnes/ha in Egypt, compared to only 4.53 tonnes/ha in Mauritania. This type of yield gap is due mainly to socio-economic factors (e.g. crop management and access to knowledge and technologies), and to a lesser extent to biophysical factors (e.g. climate, length of growing season, soil, water and pest pressure). The low rate of adoption of productive varieties and improved crop management technologies as a result of weak research and extension systems is apparent for the low yields achieved in many of the region's rice-producing countries.

PRODUCTION AND CONSUMPTION

Rice (*Oryza sativa*) is not only the staple food in many countries of the Near East region, but a key source of employment and income for rural people in rice-producing countries. It is the most widely grown crop under irrigation. Rice is grown in 16 countries in the region. Rice production in Pakistan, Egypt and Iran (Islamic Republic of) accounts for 92 percent of the region's rice production. Data in Table 1 show the evolution in the harvested area, yield and total production in some of the region's rice-producing countries in the past 42 years. Since 2000, paddy output in the region has rebounded strongly in countries that were affected by drought in the late 1990s, reflecting heavy precipitation that helped to reconstitute water reserves. This and other incentives are expected to boost rice production in the main rice-producing countries. In 2004, 2.67 percent of the rice harvested area was located in the Near East region (Table 2).

In Egypt and Pakistan, rice is considered one of the potential export crops capable of providing foreign exchange to the country. It also has an important socio-economic impact, due to the fact that a large number of the labour force is employed in the rice sector. Total consumption in Egypt for 2002 was estimated at about 3.3 million tonnes. In countries such as Morocco and Turkey, rice consumption is very low. Morocco is one of the lowest-consuming countries in the world (less than 1 kg of rice per caput per year) – clearly a major constraint to the development of rice production in the country.

Table 3 shows the level of rice consumption in some of the rice-producing countries in the Near East. During recent decades, there have been consistent increases in demand for rice, and its growing importance is evident in the strategic food security planning policies of many countries. With the exception of a small number of countries that have attained self-sufficiency in rice production, rice demand exceeds production and large quantities of rice are imported to meet demand at a huge cost in hard currency.

TABLE 1
Rice-producing countries and production in the Near East

Paddy rice	Harvested area (*ha*)			Yield (*tonnes/ha*)		Production (*tonnes*)		
	1961-2002[a]	2002	2004	2002	2004	1961-2002[a]	2002	2004
Afghanistan	187 088	135 000	-	2.87	-	367 900	388 000	-
Algeria	805	200	200	1.50	1.50	2 361	300	300
Azerbaijan	2 469	3 407	2 573	4.88	3.98	10 063	16 640	10 243
Egypt	464 119	612 616	645 930	9.14	9.80	3 038 389	5 600 000	6 352 375
Iran (Islamic Republic of)	456 995	550 000	630 000	3.85	5.40	1 597 116	2 115 000	3 400 000
Iraq	78 199	100 000	-	0.90	-	187 996	90 000	-
Kazakhstan	85 039	65 733	76 300	3.03	3.60	260 591	199 089	275 849
Kyrgyzstan	4 798	6 008	6 104	3.17	3.00	10 797	19 029	18 344
Mauritania	7 581	16 975	17 000	4.00	4.50	27 741	67 900	77 000
Morocco	5 343	5 100	2 300	3.29	7.30	23 785	16 780	16 900
Pakistan	1 861 799	2 201 000	2 519 500	2.88	2.99	4 459 130	6 343 000	7 537 100
Somalia	2 258	2 500	-	1.60	-	5 775	4 000	-
Sudan	4 101	4 762	4 800	3.31	3.28	4 283	15 748	15 748
Tajikistan	13 728	10 000	10 501	2.90	4.90	35 475	29 000	51 445
Turkey	58 105	85 000	70 000	4.71	7.00	268 583	400 000	490 000
Turkmenistan	35 782	42 000	60 000	1.07	1.83	49 848	45 000	110 000
Near East (total)	**3 161 206**	**3 840 301**	**4 045 208**	**4.00 (mean)**	**5.90 (mean)**	**10 071 217**	**15 349 486**	**18 355 302**
World (total)	**140 300 516**	**147 144 157**	**151 027 926**	**3.92 (mean)**	**4.00 (mean)**	**419 192 917**	**576 280 153**	**606 648 911**
Near East/world	**2.25%**	**2.61%**	**2.67%**	**-**	**-**	**2.40%**	**2.66%**	**3%**

[a] Mean for period 1961-2002.
Source: FAOSTAT, 2005.

TABLE 2
Rice area, yield, production, import and export for Near East countries, 2004

Paddy rice	Rice area ('000 *ha*)	Yield (*tonnes/ha*)	Production ('000 *tonnes*)	Imports ('000 *tonnes*)	Exports ('000 *tonnes*)
Egypt	645.9	9.83	6 352.0	2.0	1 000.00
Iran (Islamic Republic of)	630.0	5.4	3 400.0	972.8	0.18
Mauritania	17.0	4.53	77.0	19.6	0.00
Morocco	2.3	7.3	16.9	1.5	0.00
Pakistan	2 519.0	2.99	7 537.0	0.4	1 817.00
Sudan	4.8	3.20	15.7	49.0	0.00
Turkey	70.0	7.0	490.0	103.9	0.47
Total	**3 889.0**	**4.6**	**17 888.6**	**1 149.0**	**2 818.00**

Source: FAOSTAT, 2005.

TABLE 3
Rice consumption in some Near East rice-producing countries, 2002

Country	Population (*millions*)	Total milled rice consumption ('000 *tonnes*)	Domestic milled rice production ('000 *tonnes*)	Milled rice imports ('000 *tonnes*)	Milled rice exports ('000 *tonnes*)	Rice consumption per caput (*kg/person*)
Egypt	70.5	3 283.0	3 735.0	1.7	1 065.0	46.50
Morocco	30.0	14.0	11.2	2.9	-	0.46
Turkey	70.3	583.0	240.0	344.9	2.2	8.29
Pakistan	149.9	2 815.0	4 481.0	14.2	1 680.0	18.00
Iran (Islamic Republic of)	68.0	2 844.0	1 926.0	919.5	1.4	41.00
Mauritania	2.8	92.6	51.6	40.9	-	33.00
Sudan	32.8	41.4	10.5	30.9	-	1.26
Total	**424.3**	**9 673.0**	**10 455.3**	**1 355.0**	**2 748.6**	**22.80**

Source: FAOSTAT, 2005.

PRODUCTION STATUS IN MAJOR RICE-PRODUCING COUNTRIES OF THE NEAR EAST

Egypt

Rice is one of the major field crops in Egypt. It occupies about 0.65 million ha, produces approximately 6.4 million tonnes of rough rice annually (RRTC, 2005) and contributes about 20 percent to per caput cereal consumption. The country has several production zones and ranks as one of the highest in the world in terms of productivity per unit area. Rice area has significantly increased from 464 000 ha (average for 1961-2000) to about 646 000 ha in 2004, with the total increase estimated at about 39 percent. Oad and Rajab (2002) put this expansion down to:

- the removal of government regulations on crop choices by farmers in the mid-1980s;
- the relative profitability of rice on local and international markets;
- the food security associated with rice as a home-consumption crop; and
- the government support of rice prices relative to cotton through import tariffs.

Generally speaking, there is limited potential for further increase of the rice area in Egypt, due to the limited supply of irrigation water. A number of other factors, such as soil type and climate, also determine suitable areas. Economic factors, such as yield, cost, farmgate price and net return, affect a farmer's decision on whether to cultivate rice or not.

Iran (Islamic Republic of)

Rice is the second main crop consumed in Iran (Islamic Republic of), after wheat. Production of paddy rice is currently around 3.4 million tonnes from a cropped area of 630 000 ha, all of which is irrigated. Production units are essentially small with 70 percent having less than 1 ha. Yields from traditional rice genotypes are 2 to 4 tonnes/ha, in comparison with 5 to 7 tonnes/ha for high-yielding genotypes. About 75 genotypes are grown in the country. The major rice-producing region (in Gilan and Mazandaran provinces north of the country) is located between the Alborz Mountains and the Caspian Sea. This humid region – with its suitable soils and heavy rainfall – accounts for 73 percent of the country's total rice production. Increased production of rice in Iran (Islamic Republic of) is due not only to such conditions and increased land utilization, but to mechanization, use of chemical fertilizers and insecticides, improved seeds and the introduction of high-yielding genotypes. The main factors preventing fundamental development of the agricultural sector, including rice production, are:

- lack of water resources;
- soil conditions;
- mode of land ownership;
- seed quality; and
- production technology and management.

The rice production season in Gilan and Mazandaran begins in May and the planting period lasts slightly more than 6 weeks. Harvest starts between September and October, with some areas harvested in late October due to the cooler weather and lower rainfall (Shariati, 2003).

Pakistan

Pakistan produced 7.5 million tonnes in 2004, corresponding to average paddy yields of 2.99 tonnes/ha. Rice cultivation is concentrated mainly in Punjab (59.5 percent) but it is not the only production area (Ahmed, 2003). Much of the growth in irrigated area in Asia since 1980 is the result of tubewells. In Pakistan, the canal-irrigated area declined in absolute terms between 1982 and 1995, while tubewell irrigation – either by itself or in conjunction with canals – increased; consequently, total irrigated area increased by over 100 percent during this period. However, the increase in rice productivity in the late 1990s was due to the introduction of short-cycle genotypes, improved water management, the application of fertilizers and improved plant protection. The country's rice area increased threefold over 54 years: from approximately 0.8 million ha to about 2.4 million ha (Ahmed, 2003).

Turkey

The rice area in Turkey is approximately 70 000 ha (compared to 9.3 million ha of wheat and 3.6 million ha of barley in 2004). The rice area varies between 40 000 ha (1991) and 70 000 ha (2004), depending on water availability and government policies. In 2002, it was a total of 60 426 ha distributed over six major rice-producing zones, of which the Marmara region alone accounted for approximately 62 percent of the country's total harvested area and produced nearly 50 percent of the country's total production.

Annual milled rice production ranges between 150 000 and 240 000 tonnes, which is not sufficient for domestic consumption. This deficit is covered by imports, which reached 103 900 tonnes in 2004 (i.e. more than total domestic production). Rice imports have since continued to increase. Productivity is also increasing progressively (reaching 7.0 tonnes/ha in 2004), as is the harvest area (70 000 ha) and production (490 000 tonnes).

GERMPLASM AVAILABILITY AND VARIETAL DEVELOPMENT

Varietal development is ongoing in many rice-producing countries in the region, with research institutes focusing on market-oriented germplasm. Planted varieties in Near East countries include *japonica*, *indica* and aromatic; however, the majority are short-grain *japonica*. Aromatic rice varieties are found in Pakistan and Iran (Islamic Republic of).

In Egypt, there was great progress in rice yield during the period from 1990 to 2004 (Table 4). This progress was mostly due to the development and release of new improved short-duration varieties with high yield potential, early maturity and good resistance to blast. These varieties are widely accepted by farmers and consumers. Precise actions were taken to achieve the high yields of the Egyptian varieties:

- Release and spread of new short-duration high-yielding varieties: Giza177, Giza178, Sakha101, Sakha102, Sakha103, Sakha104, Giza182 and Egyptian Jasmine.
- Transfer of appropriate technology to the farming community in order to improve crop management.
- Monitoring of production constraints and farmers' problems during the season with prompt follow-up action by various agencies under the umbrella of the National Rice Campaign.

In Morocco, several Italian, French and Egyptian varieties have been introduced or produced locally (Table 5). In Turkey, numerous *japonica* varieties have been introduced and released for production in the different regions of Turkey: Ribe, Rocca, Baldo and Veneria from Italy; Plovdiv, Rodina and Ranballi from Bulgaria; and Krasnodarsky-424 from Russia. There are a further 500 to 600 lines from the national crossing programme. Local and introduced materials from the European rice-growing countries are also stored in the national gene bank of Turkey (Table 6).

In Pakistan, four main types of germplasm are commonly grown. The fine types are Basmati super, Basmati 385 and Basmati 2000, while IR 6 is a coarse type and a common variety. Varietal development is a continuous programme and research institutes are focusing on the market-oriented germplasm. Efforts are being made to introduce hybrid rice; in this regard, research work is under way in the public and private sectors with the collaboration of Chinese scientists.

In Iran (Islamic Republic of), the most popularly grown local varieties are Hassan Sarai, Domsiah, Binam, Hassani, Salari, Anbarbo and Sang Tarom (Table 7). Despite the low yields of these local varieties (averaging 2.5-3.5 tonnes/ha), they have excellent quality traits

TABLE 4
Yield and ancillary traits of the new released rice varieties in Egypt

Variety	Yield (*tonnes/ha*)	Duration (*days*)	Height (*cm*)	Blast L	Blast N	Grain type	Milling (*%*)
Improved varieties							
Giza 177	10.7	125	100.0	3	R	Jap. (Sh)	73
Giza 178	12.1	135	100.0	2	R	Jap. (Sh)	71
Sakha 101	11.5	140	90.0	2	R	Jap. (Sh)	72
Sakha 102	10.8	125	105.0	2	R	Jap. (Sh)	72
Sakha 103	10.9	120	99.0	2	R	Jap. (Sh)	72
Sakha 104	11.4	132	105.0	2	R	Jap. (Sh)	71
Giza 182	11.7	129	94.0	2	R	Ind. (L)	70
Egyptian Jasmine [a]	9.5	150	95.0	1	R	Ind. (L)	65
Average	**11.1**	**135**	**98.5**	**1-3**	**R**	**Sh-L**	**65-73**
Old varieties							
Giza 171	7.3	160	140.0	7	S	Jap. (Sh)	72
Giza 176	8.7	150	100.0	5	S	Jap. (Sh)	69
Giza 181	9.1	150	95.0	2	R	Ind. (L)	68
Average	**8.4**	**153**	**112.0**	**2-7**	**R-S**	**Sh-L**	**68-72**

[a] Aromatic rice.

(aroma and moderate amylose content [Ac], preferred by consumers). More than 70 percent of the total rice area in Iran (Islamic Republic of) is under these varieties, characterized by tall stature (125-135 cm) and sensitivity to lodging. They have a long slender grain, head rice recovery of 60 to 63 percent, intermediate Ac, aroma and elongation qualities. They are also susceptible to blast and stem borer.

In Mauritania, through collaboration with international institutes of research and the Africa Rice Center

TABLE 5
Varieties inscribed in the national official catalogue in Morocco

Variety	Yield (*tonnes/ha*)	Duration (*days*)	Lodging	Blast	Grain type
Triomphe	6.6	143	R	S	Jap. (Sh)
446	6.2	118	PR	S	Ind. (L)
Dinar	6.5	139	PR	PS	Jap. (Sh)
Hayat	6.8	129	R	PS	Jap. (Sh)
Kanz	6.6	129	R	PS	Jap. (Sh)
Samar	7.0	135	R	PS	Jap. (Sh)
Maghreb	7.1	118	R	T	Ind. (L)
Bahja	7.13	118	R	T	Ind. (L)
Nachat	7.29	118	R	T	Ind. (L)
Farah	10.0	135	R	R	Ind. (L)
Oumnia	9.0	130	R	T	Ind. (L)
Gharbia	9.5	130	R	T	Ind. (L)
Zena	7.9	114	R	T	Ind. (L)
Riva	8.0	116	R	T	Ind. (L)

Note: R = Resistant; PR = less resistant; S = sensitive; PS = less sensitive, T = tolerant.

TABLE 6
Some developed rice varieties in Turkey

Variety	Grain yield potential (*tonnes/ha*)	Duration (*days*)	Plant height (*cm*)	Grain type
Trakya	8.5	128	113	Jap. (Sh)
Ergene	7.0	117	100	Jap. (Sh)
Meriç	8.2	125	110	Jap. (Sh)
İpsala	8.2	125	110	Jap. (Sh)
Altınyazı	7.5	127	112	Jap. (Sh)
Sürek-95	8-10	130	100	Jap. (Sh)
Osmancık-97	8-10	130	95	Jap. (Sh)
Kıral	9-10	125	90	Jap. (Sh)
Demir	10-12	135	85	Jap. (Sh)
Yavuz	8-9	130	100	Jap. (Sh)
Neğış	7-8	126	106	Jap. (Sh)
Gönen	7-8	126	108	Jap. (Sh)
Kargı	8.0	125	110	Jap. (Sh)

TABLE 7
Local rice varieties under cultivation by Iranian rice farmers

Variety	Yield (*tonnes/ha*)	Growth duration (*days*)	Plant height (*cm*)	Amylose content	Grain length	Grain type
Hassan sarai	3.5-4	120-125	135	20	Very long	Indica
Domsiah	3.5-4	130-135	130	20	Very long	Aromatic
Binam	3.5-4	120-125	135	21	Medium	Aromatic
Hassani	3-3.5	105-110	115	22	Short	Japonica
Salarie	3-3.5	125-130	140	23	Very long	Indica
Anbarbo	2.5-3	120-125	130	19	Medium	Japonica
Sang tarom	3-3.5	115-120	125	20	Long	Aromatic

(WARDA), researchers have developed new high-yielding varieties adapted to the country's agro-ecological conditions. The national requirement for certified rice seeds is about 1 500 to 2 000 tonnes per year, while national seed production is between 900 and 1 300 tonnes. The deficit is filled each year by importation from Senegal: 200 tonnes in 1998, 400 tonnes in 1999 and 800 tonnes in 2000. The following varieties perform well in Mauritania:

- Short-day varieties (e.g. Sahel 108, IR 1561 and IR 64): yields can reach 10 tonnes/ha in research stations.
- Long-day varieties (e.g. Sahel 202 and Sahel 201): yields can reach 11 tonnes/ha.

GENERAL CONSTRAINTS CONCERNING RICE PRODUCTION

Climatic constraints

- Low temperature: A major constraint, especially for late-sowing varieties.
- High temperature: At anther development stage, strong heat causes a high percentage of sterility, reaching 100 percent at temperatures of 39°C in the dry season.
- Dry and hot winds: During flowering, dry hot winds dry up panicles and can cause sterility of spikelets.

Soil and water constraints

- Salinity: An important constraint in many countries in the Near East; the use of improper irrigation without drainage can encourage waterlogging, resulting in salinity build-up and other mineral toxicities.
- Irrigation water: Causes soil degradation because of high charges of sodium bicarbonates, which lead to a long-term phenomenon of iodination, which may destroy the superficial layer of soil and organic matter and help the pH to rise.

Biological constraints

- Weeds: Reduce rice yields by competing for space, nutrients, light and water and by serving as hosts for pests and diseases. Under farmers' conditions, weed control is not usually done properly or timely, resulting in severe yield reduction. Weeds spread due to bad land-levelling, improper irrigation methods and inappropriate agricultural techniques (seeds mixed with weeds, bad soil-tilling, inappropriate methods of sowing, and no application of crop rotation). Various weed control methods, including complementary practices, hand weeding, mechanical weeding, chemical weeding and integrated approaches, may be used.
- Birds: In dry seasons, bird proliferation is a major constraint. Many farmers do not want to cultivate their crop during dry periods because of the risk of bird damage.
- Field rats: In some places, they can be harmful and may devastate farms.
- Diseases: Rice can be host to numerous diseases and insect pests. The major diseases causing economic losses in any rice-growing country in the region are: blast, bacterial blight, bacterial leaf streak and bacterial sheath rot. Many virus diseases of rice have also been identified.

Socio-economic constraints

- Supply of goods and agricultural equipment: Fertilizers are very expensive and not always available. There is an insufficient quantity of certified seeds, obliging some producers to buy bad quality seeds.
- Rehabilitation of agricultural perimeters: Perimeters are poorly constructed and not long-lasting, because of the absence of norms of construction.
- Agricultural credit: Problems include: late credit grants, poor capacity for financing agricultural campaigns, complicated procedures for obtaining loans, difficulties related to credit recovery, and weak credit capacity to purchase agricultural equipment.

CHALLENGES AND OPPORTUNITIES FOR A SUSTAINABLE RICE-BASED PRODUCTION SYSTEM

In the Near East and associated countries, rice is grown mostly under irrigated conditions. The stagnation in the expansion of rice harvested area in most of the countries observed from 1990 to 2004 suggests that this trend is not likely to change substantially in the near future. Also, the expansion of rice area in Egypt is not sustainable in the long term due to the country's limited water resources and the increased demand for water from other sectors of the national economy. Therefore, the substantial and sustainable increase in rice production in the Near East region depends greatly on the increase in productivity of rice production systems or on yield increase.

In selected locations, such as Egypt, Iran (Islamic Republic of) and Mauritania, data reveal that climatic conditions are favourable for high crop yield. The Egyptian rice yield in 2005 was the highest not only in the region, but in the world, comparable to the Australian rice yield. This yield of 9 tonnes/ha, however, is still below the yield potential of improved *japonica* varieties. The highest recorded yield of *japonica* rice was 14.7 tonnes/ha, produced by the variety, YRL, in Riverina, Australia in 1992 (Kropff *et al*., 1994). Therefore, there are still large yield gaps in rice production in the Near East and associated countries. The narrowing of the yield gap could substantially increase the productivity of the rice production systems in the region. According to Duwayri, Tran and Nguyen (1999), the rice yield gap has three components:

A. The difference between the potential yield of existing varieties and the theoretical maximum yield. Known also as the "potential yield gap", it could be narrowed with the development of rice varieties with higher-yielding potential.
B. Differences in non-transferable factors, such as environmental conditions and built-in component technologies available at research stations. This gap, therefore, cannot be narrowed or is not exploitable.
C. Differences in management practices. Known also as the "yield gap at field level", it is the result of suboptimal crop management practices, and could be closed by adoption of improved crop management practices and systems.

In summary, the development and use of a new generation of rice varieties in order to narrow gap "A", and the development and use of improved crop management systems in order to narrow gap "C" are the technical opportunities for increasing the productivity of rice production systems in the Near East and associated countries.

TECHNOLOGIES FOR INCREASING RICE YIELD

In Pakistan and Iran (Islamic Republic of), the most popular or dominant rice varieties are *indica* and aromatic types. In Egypt, Morocco and Turkey, the dominant rice varieties are *japonica*, while in Mauritania, Iraq and Sudan, *indica* varieties are popular. When implementing a strategy to narrow the yield gap in the Near East region and associated countries, these factors must be taken into account.

New generation of rice varieties

A series of improved or high-yielding rice varieties have been developed and released for cultivation by national and international breeding programmes since the early 1970s. Wide adoption of these varieties would increase productivity. Scientists at the International Rice Research Institute (IRRI) have continued working to increase the genetic yield potential of tropical rice through the concept of new plant types (NPTs), which have the potential to bring yield to between 12 and 15 tonnes/ha by 2002 (Peng, Khush and Cassman, 1994). Progress with NPTs, however, has been slow. Scientists from several research centres are working on modifying the photosynthetic pathway of the rice plant from C3 to C4 – as in maize plants – to achieve more efficient use of sunlight energy. To date, biotechnological tools have been used mainly for the breeding of transgenic varieties with better resistance to insects, diseases and herbicides, and with a higher concentration of vitamin A in the rice grain (Khush and Brar, 2002). Recently, it was announced that scientists could develop transgenic rice with better tolerance to drought and salinity.

At present, hybrid rice is the only readily available advanced breeding material for increasing productivity over improved or high-yielding varieties. The national rice programme in Egypt, with assistance from the FAO project, TCP//EGY/2801, recently developed two hybrid combinations: SK 2034H and SK 2046H. Under normal soil conditions, SK 2034H outyielded Giza 178 by 29.9 percent, while under saline soils, it outyielded Giza 178 by 31.7 percent. Similarly, SK 2046H outyielded Giza 181 by more than 25 percent. This is indication that the development and use of hybrid rice is a viable option for increasing the productivity of the rice production systems in the region and narrowing the potential yield gap.

Integrated crop management

The yield gap due to differences in management practices results mainly from numerous deficiencies arising from inadequate crop management practices. During the 1970s and 1980s, technology production packages were formulated and transferred to farmers for the cultivation of high-yielding rice varieties under different ecosystems in different places. The application of these packages has helped to increase rice yield, but it has also produced negative effects on sustainable rice production – for example, new pest biotypes and increased nutrient deficiency of phosphorus, potassium, zinc and other nutrient elements (Tran and Ton That, 1994). Integrated pest management (IPM) and integrated nutrient management (INM) systems were developed and transferred to rice farmers. IPM systems are economically advantageous and also environmentally friendly, as they help to minimize the harmful effects of pesticides on the environment and human health (Kenmore, Gallagher and Ooi, 1995), while INM systems promote the balanced application of fertilizers and the integration of organic fertilizer (green manure, composts etc.) into the provision of nutrients to the rice crops (Shastry *et al*., 1996). The application of rice integrated crop management (RICM) systems increases rice yield and reduces costs and environmental degradation through more efficient application of inputs.

The application of RICM systems therefore offers great potential in terms of narrowing the yield gap at field level, and the development and use of RICM systems is another technological option for increasing the productivity of rice production systems in the region. The experience gained through the development and application of crop management systems in rice production (in particular, IPM and INM) points towards the development of productive and environmentally friendly RICM systems.

Integrated nutrient management

Nitrogen is the nutrient most frequently responsible for limited rice production in sandy soils. There should be approaches to regulate the timing of N application (based on the needs of the rice plant) to increase the efficiency of the plant's use of applied nitrogen. Many rice farmers use very small amounts for various reasons:

- Lack of availability
- Shortage of cash
- Poor yield response
- High risk involved in application

In addition to chemical fertilizers, there are good opportunities for applying organic manure to rice fields.

Efficient water use in irrigated agriculture

In the arid regions of western Asia and North Africa, irrigation development has been very limited in recent years: the accessible water sources have already been tapped and the remaining sources are expensive to develop. At present, about 22 million ha of irrigated land are located in western Asia and North Africa. There is no doubt that the spread of irrigation has made a major contribution to the remarkable increases in agricultural output in the tropics.

There is nevertheless widespread dissatisfaction with the performance of irrigation projects, whether performance is measured in terms of achieving planned targets or in terms of the production potential created by physical works. Furthermore, suboptimal performance is observed in irrigation systems of all types and sizes, including the small farmer-managed systems in Pakistan. According to a recent report, irrigation efficiency is as low as 50 percent in Pakistan (ADB, 1991). The inefficiencies are described below:

- Actual irrigated area is often much less than the area commanded.
- Water deliveries rarely correspond in quantity and timing to crop requirements, resulting in low cropping intensity and low productivity.
- Sharp inequities frequently exist in water supplies to farmers in the head reaches of the irrigation system and those located downstream.
- Lack of maintenance causes many systems to fall into disrepair, further inhibiting performance. As a result, over time, distribution channels fill up with silt, increasing the likelihood of breaching, damaging outlets and leading to salt build-up in the soil.

These trends underlie major concerns about the sustainability of irrigation. Indeed, worldwide, an estimated 150 million ha – about 65 percent of the world's total irrigated area – need some form of upgrading to remain productive.

Excessive irrigation and poor drainage raise the water table, bring soluble salts to the surface and may adversely affect yields on irrigated land. Most irrigation systems are created for a primary public health objective: to improve human nutrition. Their success in attaining this objective is sometimes reduced by negative impacts on health.

The major challenges in irrigation for rice cultivation are:

- development of farm-water reservoirs for water harvesting;
- selection of drought-tolerant varieties; and
- increased water-use efficiency (good land-levelling and subsoiling – requisites for proper irrigation scheduling).

Generally speaking, for sustainable increase in rice production in the Near East region, strategies must focus on:

- formulation of appropriate government policies to support the development of rice production programmes;
- increase in rice yield through development and dissemination of hybrid rice and rice integrated crop management systems;
- improvement of post-harvest technology through research and extension; and
- provision of infrastructure and accessibility to inputs.

UTILIZATION OF RICE BIOMASS TO INCREASE EMPLOYMENT AND INCOME WHILE REDUCING POLLUTION

Agricultural residues are used in a broad sense to include waste from agriculture and agro-industries. They consist of unused excess residues from growing and processing raw agricultural products, such as fruits, vegetables, poultry, fish, trees and rice straw. Residues are end-products of production and consumption that have not been used or recycled. They are none-product flows of material and energy whose economic value, at the present level of knowledge, is less than the cost of collection and transformation for use; they are therefore discarded as waste. The volume of composition of residues could be reduced by converting them into a usable product – if the value of that product exceeds the costs of conversion. This could help solve the unemployment problem through the establishment of small projects for converting agricultural waste.

If residues can be used for human benefit, they are no longer "waste", but a new "resource". By using all or a part of the waste, disposal becomes beneficial; furthermore, it would reduce pollution caused by waste disposal. The success of residue utilization depends on:

- the beneficial use;
- adequate markets;
- the availability of suitable technology to process the residue under different conditions; and
- an overall enterprise that is socially and economically feasible.

The generation of residue (in terms of quantity and quality) from agriculture and the agro-industry is dependent on a range of factors:

- type of raw materials;
- production processes;
- price of inputs and products;
- regulations affecting product quality and use; and
- constraints imposed upon disposal of residues.

Efforts are needed to develop technologies and institutional arrangements to optimize the use of residues from agricultural production. Residues must be considered as a potential resource rather than undesirable waste.

CONCLUSIONS

Rice is one of the most rapidly expanding sources of food in several Near East countries; it has a strategic role in the food security of the region. In addition, increases in rice production and support to the diversification of the rice-based system, including the utilization of by-products in the rice ecosystem, are required to meet demand and enhance the income of small farmers. It will not be possible to do this by extending the crop into newer areas, because of the scarcity of irrigation water. A number of technical and social constraints also apply.

Various factors currently affect rice production and contribute to the yield gap in some countries of the Near East region. Recognized constraints to rice-based production systems include:

- limitation of water supply and inadequate water management, resulting in low efficiency of water use;
- inefficient drainage systems, resulting in extensive soil salinity/alkalinity problems;
- declining soil fertility (insufficient supplies of fertilizer) and improper land management;
- insect pests and diseases (lack of pesticides);
- poor quality seed (short supply of improved and quality seed);
- high post-harvest losses; and
- lack of specific and encouraging policies supporting rice farmers.

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Difficultés et perspectives liées à un accroissement durable de la production rizicole au Proche-Orient

Au Proche-Orient, le riz occupe la troisième place (après le blé et le coton) pour ce qui est de la superficie cultivée. Il joue un rôle important dans la stratégie engagée en vue de lutter contre les pénuries alimentaires, et tous les ans environ 3,9 millions d'hectares sont affectés à cette culture. La production totale atteint environ 17,9 millions de tonnes, la moyenne sous-régionale de productivité étant de 4,6 tonnes à l'hectare.

Les zones irriguées de la région sont propices aux rendements très élevés. Toutefois, les rendements varient considérablement d'un pays à l'autre. Cette variabilité est due aux différentes conditions socio-économiques (gestion des cultures, accès aux connaissances et aux technologies agricoles) et dans une moindre mesure aux facteurs biophysiques (climat, durée de la période de croissance, sols, ressources en eau, pressions exercées par les ennemis des cultures, etc.)

On note un faible taux d'adoption des variétés productives et des technologies d'amélioration de la gestion des cultures, que l'on peut attribuer aux faiblesses de la recherche et des systèmes de vulgarisation. Les rendements sont donc faibles dans de nombreux pays producteurs de riz. L'élaboration de nouvelles variétés est en cours dans de nombreux pays producteurs, les instituts de recherche s'orientant surtout sur un matériel génétique destiné au marché.

La superficie cultivée est demeurée inchangée dans la plupart des pays, au cours de la période 1990-2004, ce qui laisse penser que dans un proche avenir cette tendance pourrait évoluer. Ainsi, à l'avenir, un accroissement substantiel et durable de la production au Proche-Orient sera fortement tributaire d'une productivité accrue des systèmes de production du riz ou de rendements plus élevés.

Le présent document fournit des recommandations relatives à certaines mesures efficaces pour accroître la productivité du riz et réduire l'écart des rendements au Proche-Orient afin de satisfaire la demande de cette céréale dans la région

Retos y oportunidades en relación con el aumento sostenible de la producción del arroz en la región del Cercano Oriente

El arroz constituye el tercer cultivo en orden de importancia, después del trigo y el algodón, en la región del Cercano Oriente por lo que se refiere a superficie sembrada. Desempeña una función trascendental en la estrategia para remediar las escaseces alimentarias, ocupando en torno a 3,9 millones de hectáreas al año. El total de la producción asciende a unos 17,9 millones de toneladas de arroz con una productividad media subregional de 4,6 toneladas/ha.

La agroecología de riego en la región favorece la obtención de rendimientos muy elevados, pero existen grandes variaciones en los rendimientos del arroz entre los distintos países. Esta variabilidad se debe a las diferencias derivadas principalmente de factores socioeconómicos (gestión de cultivos, acceso y utilización de conocimientos y tecnologías) y, en menor medida, de factores biofísicos (clima, duración de la temporada de cultivo, el suelo, el agua y la presión de las plagas).

Debido a los deficientes sistemas de investigación y extensión, la adopción de variedades productivas y tecnologías mejoradas de gestión de cultivos es escasa y, como resultado, muchos países productores de arroz registran bajos rendimientos. Hay en marcha proyectos para la obtención de variedades en muchos países productores de arroz, donde los institutos de investigación centran mayormente su atención en el germoplasma orientado al mercado.

El estancamiento de la expansión de la superficie cultivada de arroz registrado en la mayoría de países durante el período de 1990-2004 apunta a que en un futuro próximo esta tendencia podría cambiar. Por ello, en el futuro, conseguir aumentar de forma importante y sostenible la producción de arroz en la región del Cercano Oriente dependerá en gran medida del incremento de la productividad de los sistemas de producción del arroz o del aumento de los rendimientos.

En este documento se exponen recomendaciones sobre algunas de las medidas eficaces que pueden adoptarse para incrementar la productividad del arroz y disminuir la brecha de rendimientos en el Cercano Oriente con objeto de satisfacer la demanda regional de este cultivo.

Sustainable rice production in Europe

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CURRENT SITUATION OF RICE PRODUCTION IN THE EUROPEAN REGION

Paddy rice production in the European region, including the Commonwealth of Independent States (CIS), amounts to around 4.3 million tonnes, i.e. less than 1 percent of world production. Of the region's 45 member countries, 17 are rice-producing countries. Rice is not a major crop in European agriculture; nevertheless, it has become a traditional part of agriculture in some specific locations of (mainly) southern Europe since its introduction in the fifteenth century. Rice production is usually located along river valleys and deltas or lakes: the Tejo and Mondego valleys in Portugal; the Guadalquivir valley, Albufera lake, the Aragon area and the Ebro delta in Spain; the Rhône delta in France; the Po valley in Italy; the Thessalonica area in Greece; around Plovdiv and Haskovo along the Maritsa river in Bulgaria; the Danube valley in southern Romania; Edirne, Samsun, Sinop, Çorum, Diyarbakir and Balikesir provinces in Turkey; and the Kuban valley in the Russian Federation.

In 2005, rice production in the European region was characterized by the impact of the drought that occurred in the Mediterranean Basin. This reduced the rice cultivated area, yields and production in European Union (EU) member countries,[1] and in countries of southeast Europe.[2] In contrast, rice production in the Russian Federation and Ukraine continued to increase. Italy remains the most important rice producer (over 1.3 million tonnes) in the EU, followed by Spain (approx. 850 000 tonnes) (Table 1).

In Turkey, rice production continues to expand. Producers benefit from a government scheme whereby import licences for traders are dependent on the purchase of locally produced rice.

In the central Asian subregion,[3] harvested rice area continues to decline (with the exception of Turkmenistan), but yields improve; consequently, production remains at the level of recent years.

In general, rice yields in Western Europe are much higher than in Eastern Europe and the CIS. Within the EU, yields are highest in Greece and Spain, while in the rest of the European region yields are highest in Turkey and in The former Yugoslav Republic of Macedonia.

Average rice yield in the EU increased steadily from below 6.0 tonnes/ha in the early 1990s to about 6.6 tonnes/ha in 2004. In Eastern Europe, average rice yield in many cases remained below 3.0 tonnes/ha until 1997/98. Average rice yield has since increased and now stands at around 4.0 tonnes/ha.

Although rice is not a staple food crop in Europe, demand for human consumption continues to increase and imports of rice remain high. Rice consumption in the region increases steadily: from around 3.4 million tonnes in 1994 to 4.7 million tonnes in 2003. In the same period, average annual per caput rice consumption increased from 3.5 to 5.3 kg. Rice consumption in EU member countries currently stands at 2.4 million tonnes, and FAO estimates that the EU (25) will import around 1 million tonnes of milled rice in 2006. In 2003, CIS countries consumed about 1.4 million tonnes of milled rice, half of which in the Russian Federation.

The consumption of long-grain *indica* rice has surpassed the consumption of round- to medium-grain *japonica* rice, which is traditionally produced and consumed in the Mediterranean region. Demand in north European countries is almost entirely for *indica* type grains. Furthermore, consumption patterns are changing, with growing interest in special rice varieties, such as aromatic rice (jasmine and basmati), wild rice and coloured rice.

CONSTRAINTS TO SUSTAINABLE RICE PRODUCTION IN EUROPE

European rice production is concentrated in areas with a temperate-continental climate or Mediterranean climate, with warm and dry summer, preceded and followed by periods of low temperature. Main rainfall occurs during the first stages of crop development (April-June) and in the harvesting period (September-October). The

[1] France, Greece, Hungary (since 2004), Italy, Portugal, Spain.
[2] Bulgaria, The former Yugoslav Republic of Macedonia, Romania.
[3] Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.

TABLE 1
Rice (paddy) harvested area, yield and production in the European region

	Area harvested (*ha*)		Yield (*kg/ha*)		Production (*tonnes*)	
	2002-04	2005	2002-04	2005	2002-04	2005
EU:						
France	19 230	18 000	5 669	5 722	109 020	103 000
Greece	23 045	24 000	7 207	7 250	166 000	174 000
Hungary	2 288	3 000	4 520	3 333	10 321	10 000
Italy	222 359	222 000	6 410	6 171	1 425 715	1 370 000
Portugal	25 487	25 000	5 793	4 800	147 654	120 000
Spain	117 489	117 000	7 302	7 230	858 107	845 900
Subtotal (EU)	**409 898**	**409 000**	**6 635**	**6 413**	**2 716 817**	**2 622 900**
CIS:						
Azerbaijan	3 159	2 313	4 446	5 267	14 178	12 183
Kazakhstan	75 178	75 000	3 306	4 133	249 426	310 000
Kyrgyzstan	6 285	6 500	3 047	3 077	19 166	20 000
Russian Federation	132 700	125 000	3 563	3 920	470 630	490 000
Tajikistan	11 302	10 000	4 764	3 200	53 687	32 000
Turkmenistan	48 000	60 000	2 115	2 000	99 833	120 000
Ukraine	20 767	21 000	3 856	4 286	79 933	90 000
Uzbekistan	83 837	36 500	2 739	2 740	230 010	100 000
Subtotal (CIS)	**381 227**	**336 313**	**3 261**	**3 491**	**1 216 863**	**1 174 183**
Turkey	**65 000**	**80 000**	**6 241**	**6 563**	**407 333**	**525 000**
Others:						
Bulgaria	5 156	4 683	4 490	3 203	23 243	15 000
Macedonia (The former Yugoslav Republic of)	2 592	2 566	4 720	5 066	12 193	13 000
Romania	597	3 000	2 597	1 667	1 939	5 000
Subtotal (others)	**8 345**	**10 249**	**3 936**	**3 312**	**37 375**	**33 000**
Total	**864 470**	**835 562**	**5 065**	**5 212**	**4 378 388**	**4 355 083**

Note: For 2002-04, the figure is the average.
Source: FAOSTAT, 2006.

prevailing agro-ecological and climatic conditions in these areas pose major constraints to sustainable rice production: most importantly, low temperature, but also water scarcity and biotic stresses caused by diseases, pests and competition from weeds. In some cases, rice cultivation faces problems arising from soil salinity in marshlands and coastal lagoons, or deteriorated irrigation schemes.

Temperature

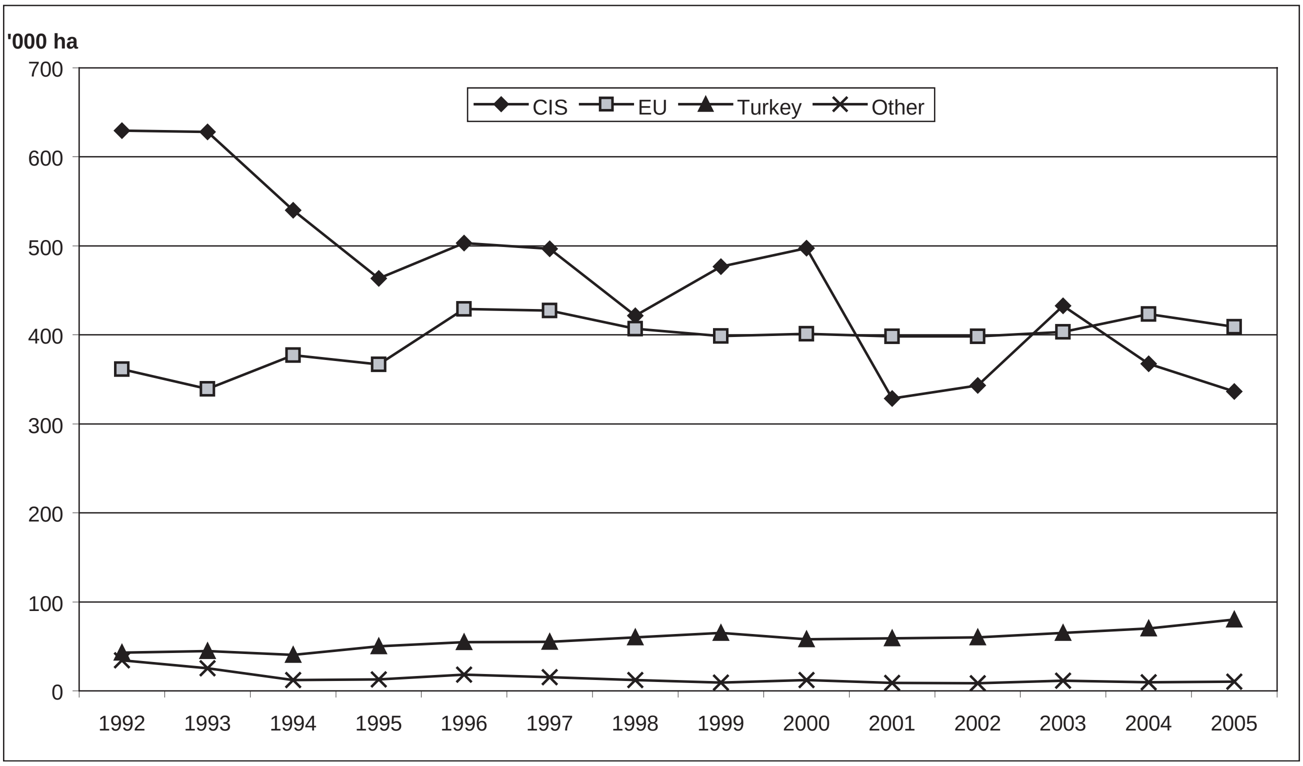
Rice plants are very sensitive to low temperature at any growth stage, in particular during seed emergence and stand establishment. In many temperate areas, such as the Mediterranean, cool weather at the beginning of the rice cropping season leads to poor stand establishment, and emergence rate may not exceed 30 to 40 percent of planted seeds. Low emergence rate is mainly due to the anaerobic conditions in paddy fields that occur at low temperatures. Farmers attempt to avoid low temperatures at the beginning of the season by delaying planting, and they compensate for stand losses with increased seed rates. However, a delay in the cropping season increases the risk of low temperatures during the reproductive stages of rice, when the death of pollen cells at meiosis stage causes grain sterility and sometimes severe damage to grain development and rice yield.

Water

Water consumption in agriculture represents about 40 percent of total water consumption in Europe, and rice is more water consuming than many other crops: in continuous flooding cultivation, it takes about six times the amount of water required by wheat. Demand for water for industrial activities, households and safe drinking water is set to increase. Governments will be obliged to place more limitations on the use of water resources, particularly in agriculture.

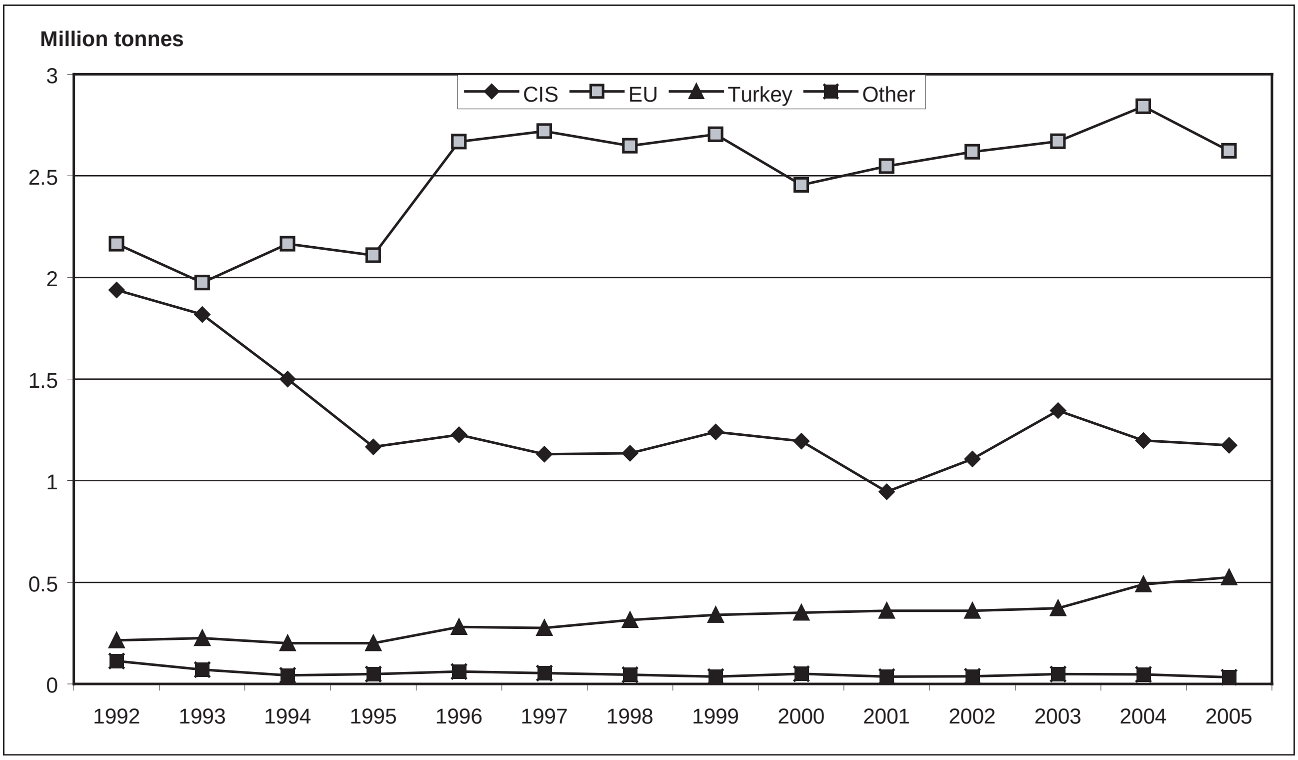
Many water problems are related to non-uniform distribution and to poor levelling of the land. Other related problems include pesticide pollution, soil erosion and

FIGURE 1
Development of rice (paddy) area harvested in the European region



Source: FAOSTAT, 2006.

FIGURE 2
Development of rice (paddy) production in the European region



Source: FAOSTAT, 2006.

deforestation, waterlogging in heavy soils and increasing irrigation costs. Farmers are, therefore, obliged to develop management strategies requiring reduced water consumption and to increase the efficiency of irrigation systems.

In continuously flooded cultivation, the availability of short-cycle and high-yielding rice is one option for reducing the amount of irrigation water used. An even more consistent reduction in water consumption could be obtained, however, by switching to discontinuous irrigation systems and developing profitable varieties suitable for these conditions. This type of water management also contributes to the alleviation of methane emissions from rice. Non-flooded conditions, on the other hand, can lead to increased competition from weeds and there is higher risk of soil salinization. The constraints on rice yield caused by weed growth and soil salinity must also be addressed as new varieties are developed.

Biotic stress

Losses in rice production as a result of diseases, pests and weeds account for about 50 percent of crop potential, in spite of current crop protection. In European rice paddies, failure to control weeds can lead to the complete loss of yield. Diseases, pests and weeds are usually controlled with pesticides and herbicides. Use of these products may, however, result in the appearance of resistant species, cause environmental pollution and disrupt the precarious balance of pests' natural enemies.

Economic factors

Various economic factors influence the sustainability of rice production – at farm level and at the level of the national economy:

- (world) market price for rice versus the cost of production;
- market protection, subsidies and tariff structures;
- economic importance of rice in the producing country;
- role of farmers in the supply chain; and
- concentration in international trade.

In Europe, farmgate prices for rice have declined in recent years, but costs for seed, fertilizer, crop protection, fuel and labour have increased. Farmers must achieve greater efficiency in rice cultivation, and in many West European countries there is a clear trend towards a reduction in the number of rice farms. At the same time, the average farm size is increasing. Operation costs for rice production remain high, making it difficult to compete with imported rice.

The EU and many other countries in the region apply protective measures for domestic production:

- compensatory payments to growers;
- guaranteed floor prices with a system of intervention storage;
- export subsidies promoting competition on third markets;
- import duties;
- administrative procedures (a potential trade barrier); and
- financial guarantees to obtain import licences.

Many countries have subscribed to the objectives of the World Trade Organization (WTO) to reduce tariffs in world trade; the system of import duties is gradually decreasing.

Under the "Everything But Arms" (EBA) programme, in February 2001 the EU made a commitment to give unrestricted, duty-free access to rice imports originating from least-developed countries (LDCs) as of 2009 (Table 2). Until then, duty-free imports will be subject to quantitative ceilings (set at relatively small volumes). Imports from LDCs which exceed the quota will progressively benefit from tariff reductions.

Environmental issues

There is increasing environmental concern about pesticide use, biodiversity, water consumption and methane gas emissions from irrigated rice fields. It is, therefore, important to promote integrated management systems, using adapted varieties and making more efficient use of inputs, including water.

TABLE 2
EC rice concessions under the EBA Preferential Access Scheme

	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
Duty-free quota (*tonnes*)	3 329	3 829	4 403	5 063	5 823	6 696	Free access
Duty reductions	none	none	none	20%	50%	80%	100%

Source: EU, 2001.

CONCLUSIONS

Rice production in Europe has a strong traditional base and is also enterprising, despite the sometimes unfavourable climatic conditions and the difficult economic context.

Strategies for sustainable rice production in Europe promote the development of integrated crop management systems: improved productivity, reduced production costs, and adoption of agricultural practices that safeguard biodiversity and the environment.

Potential for improvement lies in the selection of high-yielding varieties with good tolerance to low temperatures, better water management and improved levelling of the land. In addition, enhanced information exchange and collaboration among rice research institutions at regional and interregional level and related networks (such as MED-Rice[4]) will help to address the future challenges of European rice production.

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La production durable de riz en Europe

La situation actuelle de la production de riz en Europe varie selon les pays. Du fait de la sécheresse qui a frappé le bassin méditerranéen en 2005, la production de riz dans les États membres de l'UE a diminué ainsi que celle des pays de l'Europe du Sud-Est. Par ailleurs, en Fédération de Russie et en Ukraine, la production de riz continue à croître. Une tendance similaire est relevée en Turquie, alors que dans la sous-région de l'Asie centrale la zone cultivée en riz s'est encore rétrécie.

Le riz n'est pas une denrée de base en Europe, mais sa consommation augmente de plus en plus et les importations de riz restent élevées. La consommation de riz *indica* (long grain) a dépassé celle du riz *japonica* (grain court et arrondi) traditionnellement produit et consommé dans la région méditerranéenne. Les habitudes alimentaires évoluent aussi et les variétés particulières de riz, comme le riz parfumé ou aromatique, le riz sauvage et le riz coloré suscitent de plus en plus d'intérêt.

En Europe la production de riz est concentrée essentiellement dans les zones à climat méditerranéen. Les conditions climatiques et agroécologiques de la région représentent néanmoins une série d'obstacles pour une production durable (on peut citer principalement les températures basses, la rareté de l'eau et le stress biotique dû aux maladies, aux ravageurs et aux adventices). Les facteurs économiques tels que les cours du riz sur le marché mondial, le régime tarifaire, la protection des marchés et les subventions ont une incidence sur la durabilité de la production de riz tant au niveau des exploitations qu'au plan national. En Europe, les coûts de fonctionnement relativement élevés de la production de riz ne permettent pas de faire face à la concurrence du riz importé et de nombreux pays prennent des mesures pour protéger leur production nationale. En outre, l'utilisation de pesticides et les émissions de gaz méthane provenant des rizières soulèvent de plus en plus des préoccupations pour l'environnement.

Les stratégies de production durable adoptées en Europe encouragent l'élaboration de systèmes de gestion intégrée des cultures assorties d'une amélioration de la productivité et d'une réduction des coûts de production, ainsi que l'adoption de pratiques agricoles qui protègent la biodiversité et l'environnement.

[4] Inter-regional Co-operative Research Network on Rice in the Mediterranean Climate Areas (www.medrice.unito.it/).

La producción sostenible del arroz en Europa

La situación actual de la producción del arroz en la región de Europa varía en función del país. La sequía registrada en la cuenca mediterránea en 2005 hizo disminuir la producción de arroz en los Estados Miembros de la UE, así como en los países de Europa sudoriental, si bien, por otro lado, la producción de arroz en la Federación de Rusia y Ucrania sigue creciendo. En Turquía continúa aumentando la producción de arroz, en tanto que en la subregión del Asia central la superficie de arroz plantada ha seguido disminuyendo.

Pese a que el arroz no constituye un cultivo alimentario básico en Europa, su consumo va en aumento y sus importaciones se mantienen altas. El consumo de arroz *indica* de grano largo ha superado al consumo de arroz *japonica* de grano redondo a mediano, que se produce y consume tradicionalmente en la región mediterránea. También las pautas de consumo están cambiando y existe un mayor interés por las variedades de arroz especiales, como el arroz fragante o aromático, el arroz silvestre y el arroz colorado.

La mayor parte de la producción de arroz en Europa se concentra en zonas de clima mediterráneo. Las condiciones agroecológicas y climáticas imperantes en esta zona plantean, no obstante, importantes limitaciones para la producción sostenible de arroz, sobre todo las bajas temperaturas, la escasez de agua y el estrés biótico provocado por enfermedades, plagas y malas hierbas. También los factores económicos, como el precio del mercado mundial para el arroz, las estructuras arancelarias, la protección del mercado y las subvenciones, influyen en la sostenibilidad de la producción del arroz tanto a nivel de las explotaciones como de la economía nacional. Los costos relativamente altos de explotación para la producción del arroz en Europa dificultan la competencia con el arroz importado y, por ello, muchos países aplican medidas de protección a favor de su producción nacional. Además, hay un aumento de las preocupaciones ambientales en relación con la utilización de plaguicidas y las emisiones de gas metano procedentes de los campos de arroz de riego.

Las estrategias para la producción sostenible de arroz en Europa fomentan el desarrollo de sistemas integrados de gestión de cultivos con mejora de la productividad y costos de producción reducidos, así como la adopción de prácticas agrícolas que salvaguardan la biodiversidad y el medio ambiente.

The concept and implementation of precision farming and rice integrated crop management systems for sustainable production in the twenty-first century

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Agricultural production systems, including rice systems, have been very successful in increasing productivity and efficiency, thanks to genetic improvement, agrochemical practices, irrigation and farm machinery. However, the world population continues to grow steadily, while the resources for agricultural production diminish. Moreover, the economic pressure resulting from World Trade Organization (WTO) negotiations and increasing environmental degradation are threatening sustainable production in the twenty-first century. There have, therefore, been considerable efforts to develop innovative approaches for sustainable crop production.

In several countries in the developed world, the precision farming system (PFS) has emerged since the early 1990s in various forms, depending on the knowledge and technology available. PFS is implemented in combination with advanced information technology and full agricultural mechanization. Electronic information technology is used to collect, process and analyse multi-source data for decision-making (Sonka, Bauer and Cherry, 1997). The declining prices of agricultural products in recent years, coupled with the increase in production costs, have favoured the application of PFS in many developed countries. The importance of precision agriculture in the near future is further attested by the interest shown by NASA (National Aeronautics and Space Administration).

In many developing countries, however, there is no specific PFS programme – there is a shortage of capital, knowledge and technologies. Nevertheless, improved agricultural management is practised, exploiting available means and resources to increase agricultural productivity and production. In rice production systems, for example, farmers in developing countries use their own experience as well as recommendations from research and extension services to undertake activities in seed selection, land preparation, crop management, irrigation and harvest. The recently developed rice integrated crop management systems, which may be adapted to the social and economic conditions, are promising for effective input use, increased productivity and improved farm profits.

THE PRECISION FARMING SYSTEM CONCEPT

PFS is based on the recognition of spatial and temporal variability in crop production. Variability is accounted for in farm management with the aim of increasing productivity and reducing environmental risks. In developed countries, farms are often large (sometimes 1 000 ha or more) and comprise several fields. The spatial variability in large farms, therefore, has two components: within-field variability and between-field variability.

The precision farming system within a field is also referred to as site-specific crop management (SSCM). According to the Second International Conference on Site-Specific Management for Agricultural Systems, held in Minneapolis, Minnesota, in March 1994,

> *SSCM refers to a developing agricultural management system that promotes variable management practices within a field according to site or soil conditions.*
>
> (National Research Council, 1997)

However, according to Batte and VanBuren (1999), SSCM is not a single technology, but an integration of technologies permitting:

- collection of data on an appropriate scale at a suitable time;
- interpretation and analysis of data to support a range of management decisions; and
- implementation of a management response on an appropriate scale and at a suitable time.

In a study of PFS in developed countries, Segarra (2002) highlights the following advantages to farmers:

- Overall yield increase. The precise selection of crop varieties, the application of exact types and doses of fertilizers, pesticides and herbicides, and appropriate irrigation meet the demands of crops for optimum growth and development. This leads to yield increase, especially in areas or fields where uniform crop management practices were traditionally practised.
- Efficiency improvement. Advanced technologies, including machinery, tools and information, help farmers to increase the efficiency of labour, land and time in farming. In the United States, a mere 2 hours are sufficient to grow 1 ha of wheat or maize.
- Reduced production costs. The application of exact quantities at the appropriate time reduces the cost of agrochemical inputs in crop production (Swinton and Lowenberg-DeBoer, 1998). In addition, the overall high yield reduces the cost per unit of output.
- Better decision-making in agricultural management. Agricultural machinery, equipment and tools help farmers acquire accurate information, which is processed and analysed for appropriate decision-making – in land preparation, seeding, fertilizer, pesticide and herbicide application, irrigation and drainage, and post-production activities.
- Reduced environmental impact. The timely application of agrochemicals at an accurate rate avoids excessive residue in soils and water and thus reduces environmental pollution.
- Accumulation of farmers' knowledge for better management with time. All PFS field activities produce valuable field and management information and the data are stored in tools and computers. Farmers can thus accumulate knowledge about their farms and production systems to achieve better management.

PRECISION FARMING SYSTEM IN THE DEVELOPED WORLD

Farmers in developed countries typically own large farms (10-1 000 ha or more) and crop production systems are highly mechanized in most cases. Large farms may comprise several fields in differing conditions. Even within a relatively small field ($\leq$30 ha), the degree of pest infestation, disease infection and weed competition may differ from one area to another.

In conventional agriculture, although a soil map of the region may exist, farmers still tend to practise the same crop management throughout their fields; crop varieties, land preparation, fertilizers, pesticides and herbicides are uniformly applied in spite of variation. Optimum growth and development are thus not achieved; furthermore, there is inefficient use of inputs and labour. The availability of information technology since the 1980s provides farmers with new tools and approaches to characterize the nature and extent of variation in the fields, enabling them to develop the most appropriate management strategy for a specific location, increasing the efficiency of input application.

NEW TOOLS AND EQUIPMENT

In addition to mechanization, other tools and equipment are used in PFS in developed countries.

Global positioning system (GPS)

GPS is a navigation system based on a network of satellites that helps users to record positional information (latitude, longitude and elevation) with an accuracy of between 100 and 0.01 m (Lang, 1992). GPS allows farmers to locate the exact position of field features, such as soil type, pest occurrence, weed invasion, water holes, boundaries and obstructions. There is an automatic controlling system, with light or sound guiding panel (DGPS), antenna and receiver. GPS satellites broadcast signals that allow GPS receivers to calculate their position. In many developed countries, GPS is commonly used as a navigator to guide drivers to a specific location. GPS provides the same precise guidance for field operations. The system allows farmers to reliably identify field locations so that inputs (seeds, fertilizers, pesticides, herbicides and irrigation water) can be applied to an individual field, based on performance criteria and previous input applications (Batte and VanBuren, 1999). Perry (2005) highlights the specific advantages of GPS in farm operations:

- Farm machines are guided along a track hundreds of metres long making only centimetre-scale deviations.
- Rows are not forgotten and overlaps are not made.
- The number of rows can be counted during work.
- Tools and equipment can be operated in the same way from year to year.
- It is possible to work at night or in dirt with precision.
- The system is not affected by wind.
- An additional recorder can store field information to be used in making a map.

Sensor technologies

Various technologies – electromagnetic, conductivity, photo-electricity, ultrasound – are used to measure humidity, vegetation, temperature, vapour, air etc. Remote-sensing data are used to: distinguish crop species; locate stress conditions; discover pests and weeds; and monitor drought, soil and plant conditions. Sensors enable the collection of immense quantities of data without laboratory analysis. The specific uses of sensor technologies in farm operations are as follows:

- Sense soil characteristics: texture, structure, physical character, humidity, nutrient level and presence of clay (Chen *et al*., 1997).
- Sense colours to understand conditions relating to: plant population, water shortage and plant nutrients.
- Monitor yield: crop yield and crop humidity.
- Variable-rate system: to monitor the migration of fertilizers and discover weed invasion.

Geographic information system (GIS)

The use of GIS began in 1960. This system comprises hardware, software and procedures designed to support the compilation, storage, retrieval and analysis of feature attributes and location data to produce maps. GIS links information in one place so that it can be extrapolated when needed.

Computerized GIS maps are different from conventional maps and contain various layers of information (e.g. yield, soil survey maps, rainfall, crops, soil nutrient levels and pests). GIS helps convert digital information to a form that can be recognized and used. Digital images are analysed to produce a digital information map of the land use and vegetation cover. GIS is a kind of computerized map, but its real role is using statistics and spatial methods to analyse characters and geography. Further information is extrapolated from the analysis (ESRI, 2002). A farming GIS database can provide information on: filed topography, soil types, surface drainage, subsurface drainage, soil testing, irrigation, chemical application rates and crop yield. Once analysed, this information is used to understand the relationships between the various elements affecting a crop on a specific site (Trimble, 2005).

Variable-rate technologies (VRT)

Variable-rate technologies (VRT) are automatic and may be applied to numerous farming operations. VRT systems set the rate of delivery of farm inputs depending on the soil type noted in a soil map. Information extrapolated from the GIS can control processes, such as seeding, fertilizer and pesticide application, and herbicide selection and application, at a variable (appropriate) rate in the right place at the right time (Batte and VanBuren, 1999; NESPAL, 2005). VRT is perhaps the most widely used PFS technology in the United States (National Research Council, 1997).

Grain yield monitors for mapping

A monitor mounted on a combine continuously measures and records the flow of grain in the grain elevator. When linked with a GPS receiver, yield monitors can provide data for a yield map that helps farmers to determine the sound management of inputs, such as fertilizer, lime, seed, pesticides, tillage and irrigation (Davis, Massey and Massey, 2005).

Crop management

The precision farming system employs the innovations and technologies described above (Rickman *et al*., 1999). Thanks to satellite data, farmers have a better understanding of the variation in soil conditions and topography that influence crop performance within the field. Farmers can, therefore, precisely manage production factors, such as seeds, fertilizers, pesticides, herbicides and water control, to increase yield and efficiency. In the United States, for example, the management scheme of typical PFS comprises the following practical steps (NESPAL, 2005):

1. Determine management zones to be applied with PFS.
2. Establish yield goals.
3. Carry out soil sampling and data interpretation.
4. Make decisions regarding management of land

preparation, varieties, fertilizers and other nutrients to achieve yield goals.
5. Establish maps to discover the pest population: insects, diseases and weeds, using an integrated pest management (IPM) approach.
6. Apply precision irrigation.
7. Apply logging and automated record keeping.
8. Monitor and establish yield maps, evaluate PFS response and identify strengths and weaknesses for future improvement.

The Australian Centre for Precision Agriculture (2005) is currently focusing on the application of PFS in crop production and its site-specific crop management includes five main processes:

1. Spatial referencing. Collecting data on the spatial variation in soil and crop features requires accurate position determination in the field, using GPS.
2. Differential action. In response to spatial variability, farming operations, such as sowing rate, fertilizer, pesticide and lime application, tillage and water use, can be varied in real time across a field. Variation in treatment corresponds to the mapped variation in the field attributes measured.
3. Soil and crop monitoring. Soil and crop attributes are monitored on a finite scale. When observations are targeted with GPS, they provide data on the spatial variability of the attributes within a field.
4. Spatial prediction and mapping. Values for soil and crop attributes are predicted for unsampled locations across a field. This enables detailed representation of the spatial variability within an entire field through the creation of a smoothed map.
5. Decision support. Knowledge about the effects of field variability on crop growth – and the suitable agronomic responses – can then be combined to formulate differential treatment strategies.

In summary, PFS – also referred to as site-specific farming – is made possible by the deployment of GPS to locate sites within the fields. A computer integrates the GIS application map and the GPS receiver information, which are sent to the controller on the VRT machine, which applies variable rates in farming operations.

Adoption of PFS in developed countries

In developed countries, farmers – including rice farmers – have gradually moved from conventional highly mechanized agriculture to a high-tech precision farming system. Many farmers in the United States and Canada began using GPS with a yield monitor to produce a yield map for field improvement. Sales of yield monitors in the United States have been increasing by between 70 and 300 percent a year from 1993 to 1998 (Swinton and Lowenberg-DeBoer, 1998). Recently, PFS has focused on the variable application rates of NPK fertilizers, seeding and irrigation. The development and adoption of PFS in Europe is less advanced than in the United States and Canada, due to the relatively small size of farms in most European countries. In Japan, where the average farm size is small, not all researchers and managers believe that PFS can be deployed to increase economic returns, reduce production costs and energy inputs, and conserve the agricultural environment. However, Shibusawa (2002) reported that the concept of PFS could be implemented on small as well as large farms:

- Farm variability is a major issue and PFS is equipped to find appropriate solutions. Variability exists in three aspects: spatial, temporal and predictive.
- Variable-rate technology is used to adjust agricultural inputs (fertilizers, pesticides, herbicides, water use) for site-specific needs within fields. On small farms, inputs can be applied manually. Variable-rate technology improves yield by re-organizing technologies, plants and fields. Its application requires:
  - correct positioning in the field;
  - accurate information on the location; and
  - timely operations on the site concerned.

- Decision-support system is a computerized process offering farmers a series of choices with regard to trade-off problems, where conflicting demands must be taken into consideration, such as productivity and environment protection (Shibusawa, 2000). This approach helps farmers optimize the whole production system.

In the United States, rice farmers typically adopt all of the new technologies described (GPS, sensor technologies, GIS, VRT and yield monitors). The following field operations are performed by rice farmers in California:

- Land preparation. Laser-based tools provide productivity enhancements, especially for land-levelling and drainage. A tractor equipped with laser equipment can level land with a difference of just a few centimetres and create terraces on slopes. Good land-levelling facilitates good seed germination, efficient application of agrochemicals and water distribution in the fields.

- Land preparation, planting and field care. These operations can be done using computerized machinery equipped with GPS and GIS; time is saved and soil and labour productivity improved. GPS and GIS also help work to be done in rows resulting in precision within a few centimetres.
- Crop establishment. GPS and GIS guide seeding so that exactly the right amount is distributed in each part of a field to achieve optimal plant establishment.
- Fertilizer application. GPS, GIS and VRT help farmers apply fertilizers on time, with the right amount for each soil type, thereby increasing yield.
- Pesticide and herbicide application. GPS, GIS and VRT guide farmers to use pesticides and herbicides only where needed, resulting in lower production costs and reduced environmental pollution.
- Irrigation. Machinery and tools equipped with GPS and GIS ensure appropriate irrigation and drainage at the right time in the right place, resulting in water savings and reduced investment costs.
- Harvest. Machinery and tools equipped with GPS, GIS and yield monitor help to harvest rice fast, safely and accurately, working also at night or in dirt; yield maps can be produced for future improvement.
- Post-harvest operations. Advanced machinery and equipment increase the efficiency of post-harvest operations, resulting in high-quality rice, head rice and milling yield, and lower grain losses in processing and storage.
- Management. A computer system can create and update information on soils, water, crops, insects, diseases and herbicides for improved future management.

Nevertheless, the adoption of PFS has been limited for various reasons:

- Gathering information for devising PFS strategies is expensive and time consuming.
- The benefits of PFS are not immediately apparent, gains are spread over a long period of time and it is difficult to estimate the costs and returns to users.
- Although diminishing, the costs of PFS technologies remain high for users.

The cost-effectiveness of PFS or site-specific farming is still in question, as the prices of high technology are high and farmers' skills are inadequate to handle large amounts of field data and information. Automation of the data-processing and interpretation processes, such as simulation models and decision-support systems, needs further improvement for friendly PFS implementation (Buick, 1997). Research on the profitability of PSF has revealed the following:

- Of the sites studied for VRT application of fertilizers, 57 percent produced greater profits for site-specific farming than for uniform rate technology (URT) (Swinton and Lowenberg-DeBoer, 1998).
- A study of nitrogen fertilization on Iowa corn revealed that the economic and environmental impact in moving from URT to VRT depended heavily on the yield variability in fields (Babcock, Bruce and Pautsch, 1998).
- A study of weed control with post-emergence herbicides concluded that weed patchiness was the most important factor influencing the profitability of VRT application of herbicides, as compared to URT application over the whole field (Oriade *et al*., 1996).

These studies all focused on a single production parameter and conducted partial budgeting analysis to evaluate the profitability of PFS, ignoring the environmental, sustainability and informational issues (Ancev, Whelen and MacBratney, 2004).

As population density increases, together with food safety awareness and public concern for the environment, the precision farming system is viewed as increasingly viable. Since the concept of site-specific farming is appealing for both profitability and the environment, the widespread adoption of PFS will be realized in the near future. Cost will decrease over time as the technologies change and farmers' understanding of how to use them improves (Batte and VanBuren, 1999).

RICE INTEGRATED CROP MANAGEMENT – AN EXAMPLE OF PRECISION FARMING SYSTEM IN DEVELOPING COUNTRIES

In most of the developing world, Agricultural research and education institutes are familiar with the concept of PFS. However, the technologies and tools used in PFS in industrialized countries are beyond the reach of resource-poor farmers in developing countries. Furthermore, not only have many developing countries in Asia and Africa made slow progress in agricultural mechanization, they are also less advanced in information technology and its everyday application. Researchers and extension workers in developing countries, therefore, have developed and disseminated the integrated crop management system to improve crop management and increase yield across fields.

Spatial and temporal variability is the key to PFS. In small farms, especially in Asia and Africa, the heterogeneity of agricultural land is not important in agricultural input management, and while a site-specific approach is relevant on large farms, it is essential on small farms. Nevertheless, managing variability in terms of the timing and amount needed for specific crop growth is essential for increasing farm productivity and profits. In rice production, for example, correct fertilizer application is the most important factor for determining the final yield of rice: it affects directly grain yield, and indirectly crop establishment, panicle and grain formation, and pest and weed occurrence. Use of a chlorophyll meter and leaf colour chart for field-specific N management (as tested by IRRI – International Rice Research institute – and national research centres) has helped farmers in nitrogen fertilizer application in a number of Asian developing countries (Siddiq, Rao and Prasad, 2001).

The improvement of crop management practices among small farmers in developing countries is often not an easy task. Crop management practices must be adjusted to crop varieties, environmental factors, knowledge and market forces. Input and output prices affect farmers' decisions with regard to the level of inputs to be applied, while employment opportunities influence the time spent by farmers in crop management. The improvement of farmers' management skills through the accumulation of data and information is an important aspect of PFS and it has been integrated into the development and dissemination of rice integrated crop management (RICM) in a number of developing countries.

The concept of the RICM system

Rice farmers carry out numerous cultural operations during the growing season. These activities, separately and collectively, impact all the phases of crop development and all the yield components that ultimately determine yield. Rice integrated crop management (RICM) systems are based on the understanding that production limitations are closely linked (Clampett, Nguyen and Tran, 2002). For example, stronger seedlings from high quality seeds will not benefit yield if the crop is inadequately fertilized. Similarly, the crop cannot respond to improved fertility if it is competing with weeds or if insufficient water is supplied.

Historically, the concept of RiceCheck was presented by Mr J. Lacy, an Australian extension worker, at the first International Symposium on Temperate Rice – Achievements and Potential (Yanco, New South Wales, Australia, 21-24 February 1994) and at the FAO Expert Consultation on Technological Evolution and Impact for Sustainable Rice Production in Asia and The Pacific (Bangkok, Thailand, 29-31 October 1996). His presentations were greatly appreciated by participants.

In Australia, the RiceCheck system was developed in the mid-1980s for the management of irrigated rice production (Lacy *et al.*, 1993). The RiceCheck system is a framework for RICM and the evaluation of management results as a means to improve productivity and environmental outcomes. In this model, farmers are actively involved using discussion groups in a collaborative learning environment for improving management and yields (Clampett, Nguyen and Tran, 2002). With the application of the RiceCheck system, the average rice yield in Australia increased remarkably from 6 tonnes/ha in the mid-1980s to more than 8.5 tonnes/ha by the end of the 1990s.

The Expert Consultation on Yield Gap and Productivity Decline in Rice Production (Rome, 2000) recommended the development of RICM systems (similar to the Australian RiceCheck system) and their transfer through farmer field schools, in order to assist farmers in developing countries to narrow the yield gap in rice production and reduce rural poverty.

The development of RICM systems

The implementation of the recommendations of the Expert Consultation included collaboration between FAO and selected member countries in Asia and Latin America in a pilot test to develop and disseminate RICM systems for their possible implementation in other countries. In lowland rice production, researchers and extension officers generally provide recommendations regarding seed selection, land preparation, crop establishment, plant establishment, crop protection, nutrition management, water management, harvest management and post-harvest operations. However, the skills and knowledge in rice crop management among farmers, extension officers and researchers in many developing countries have greatly improved since the Green Revolution in the 1970s. Therefore, the development of RICM systems must focus on areas of crop management with potentially immediate and significant impacts on yield and efficiency of input application. Discussions between FAO and collaborating countries suggested that there are five essential steps for the establishment of a comprehensive RICM system, based on the framework of the RiceCheck system (Tran and Nguyen, 2001):

- Identify key management areas. Study and prioritize all factors affecting the current rice yield gap and production in the selected (or target) location.
- Quantify good management practices (GMPs) of progressive farmers. Survey and analyse the rice production technology and practices of farmers to identify differences in each key management area.
- Review available technology and knowledge. Review current knowledge based on research results, practices and experiences of researchers, extension workers and farmers.
- Develop interim GMPs. Based on steps 1, 2 and 3, collate, in conjunction with researchers, extension workers and farmers.
- Evaluate GMPs. Test, demonstrate and monitor the developed RICM system with a farmer discussion group and train extension workers and farmers.

As expected, the RICM systems developed in different collaborating countries during the pilot tests varied considerably from one country to another (Table 1).

The performance of RICM systems

- Indonesia. ICM system evaluated in 31 districts in 24 provinces throughout the country.
- Philippines. PalayCheck system evaluated with irrigated rice farmers throughout the country.
- Thailand. Thai RiceCheck system tested on 200 farmers in Pathumtani, Prachinburi, Sakhon-Nakorn and Phitsanulok provinces in the Central Plain of the country.
- Viet Nam. “3 Increases, 3 Reductions” system developed and tested with farmers in Can Tho and Tien Giang provinces in the Mekong River Delta.
- Latin America. ICM systems tested with farmers in Rio Grande do Sul (Brazil) and in Calabozo and Portuguesa (Venezuela, Bolivarian Republic of).

The results of these pilot tests on the development and dissemination of RICM systems were very positive and encouraging. They formed a major part of the keynote address (p. 1-19). Similar results were also reported by FLAR (Latin American Fund for Irrigated Rice) in July 2006 (FLAR, 2006). Below are the summaries of the results of the pilot tests on the development and dissemination of RICM systems:

- Yield of irrigated rice generally increased with RICM systems. The increase was very high in Latin America, moderate in Thailand and low in Viet Nam. In Indonesia, variable yield increases were observed, with the exception of a single case of yield reduction. In the Philippines, rice yields were positively and closely correlated with the number of management areas in the RICM system that farmers were able to achieve.
- The application of RICM systems significantly reduced the cost of irrigated rice production in Thailand and Viet Nam. In Indonesia, production costs increased in some villages and decreased in others.
- The application of RICM systems increased the profits of irrigated rice production in all countries. The profit increase was significantly high in Brazil.
- The quality of milled grains was improved with the application of the RICM system in Viet Nam.

Transforming RICM systems for precision management in the twenty-first century

The pilot tests clearly demonstrate the ability of RICM systems to improve farmers’ skills in crop management for enhancing productivity and efficiency in irrigated rice production. RICM systems increase yield, reduce costs, increase profits and improve grain quality. RICM systems must aim to improve farmers’ knowledge, not only of crop production and protection, but of the conservation of natural resources. Therefore, for each area of management during the cropping season, the RICM systems should provide, as reference, input and output recommendations: “key checks”. The input recommendations must include the type and quantity of input to be applied, as well as the timing and method for input application, while the output recommendations must include the expected results of the input application in the area of crop management. A participatory approach involving farmers, researchers and extension workers should be applied in the development of the key checks

TABLE 1
RICM systems in selected developing countries

Country	RICM system	Description of RICM system
Indonesia [a]	ICM	Six recommendations: Selection of rice varieties for high yield and seed Transplanting of young and healthy seedlings Incorporation of organic manure and basal fertilizer into soil and the use of leaf colour chart for nitrogen top-dressing Intermittent irrigation Frequent mechanical weeding Control of pests and diseases, based on a regular field observations and early warning system
Philippines [b]	PalayCheck	Eight recommendations: Use pure and high quality seeds of the best variety with at least 85% germination Level the field properly and achieve no high and low soil spots at initial flooding Sow the right amount of seeds following local planting and achieve at least 1 healthy seedling/hill at 10 days after transplanting Feed the rice plants with the right nutrients as needed; achieve at least 24 tillers/hill at panicle initiation Maintain appropriate water depth and achieve 3-5 cm water depth from early tillering to grain filling stage Apply appropriate pest management technology and ensure no significant yield loss from pests Harvest crop at the right maturity stage, i.e. 1/5 of panicle or 4-5 grains at the base of the primary panicle are in hard dough stage Thresh, clean and dry immediately before storing in clean sacks in order to achieve Premium grade 1 for paddy
Thailand [c]	Thai RiceCheck	Nine management areas: Seed selection and use Land preparation Crop establishment Nutrient management Insect pest and disease management Weed management Water management Rouging/purification of crop stand for seed production Harvest management
Viet Nam [d]	3 Increases, 3 Reductions	Five recommendations: Select new high-yielding varieties having pest resistance and high grain quality for export Apply in-row seeding with IRRI drum seeders Apply fertilizers based on soil nutrient status and leaf colour chart to estimate the N rate for top-dressing Application of IPM Harvest in time to ensure good grain quality and reduce post harvest losses
Brazil [e]	ICM	Six strategic management practices: Planting date Seeding density Pesticide-treated seeds Balanced nutrition and in quantity for high yield Early weed control Appropriate irrigation water management.
Venezuela [e]	ICM	Six recommendations: Date of planting that permits to receive maximum solar radiation during the reproductive phase N fertilizer management for high efficiency Early weed control Improved irrigation water management Use of insecticide-treated seeds to control pest outbreaks Low planting density to reduce foliar disease and cost for treated seeds.

Sources:
[a] Woodhead, 2003; Abdulrachman, Las and Yuliardi, 2005.
[b] Redona, Castro and Llanto, 2004; Cruz *et al*., 2005.
[c] Clampett, 2003; Kunnoot, 2005.
[d] Pham, Trinh and Tran, 2005.
[e] Pulver and Carmona, 2005.

in the context of group discussions. Also, the key checks should be revised each year on the basis of new results from research and new experiences gained from application in the previous year.

This requires substantial improvement to the system of collection and dissemination of information on rice, its production factors, and its technologies as well as modification of the extension systems in many countries. Progressive farmers should be trained to use computers so that they can record rice-field data to be processed and analysed for improved crop management. On a regional basis, recommendations under RICM systems are very generalized, failing to take account of the inherent variability of lands and assuming average weather. It is, therefore, recommended, in the information technology age, that agricultural administrators and researchers consider using modern PFS technologies (e.g. GPS, GIS and yield maps) in developed countries, so that they may formulate recommendations for specific locations; detect pest occurrence, drought and flash flood spots; and design appropriate management. It is also recommended that they play a coordinating role in the implementation of these new and costly technologies for a regional development plan.

CONCLUSION

The precision farming system is an innovative approach for responding to the diminishing resources, economic pressure and increased environmental degradation in agriculture. Although there are economic concerns about the use of high technological tools in agriculture, PFS, or site-specific management, is a fast-developing field in developed countries. This system has helped an increasing number of farmers in developed countries to use more effectively farm inputs, such as fertilizers, insecticides, fungicides, herbicides and irrigation water, in order to achieve increased productivity, efficiency, profits and environmental protection. The cost-benefits of PFS are under investigation, while the system is being fine-tuned for wide adoption.

Owing to limited resources and the prevailing small farm size, agricultural production systems in developing countries have employed the PFS concept differently. In developing countries, PFS is an integrated crop management system that enables farmers to close the yield gap between fields and research stations – still very large in many countries. For rice production systems in developing countries, the recent pilot tests conducted by FAO and a number of member countries had demonstrated the potential of RICM systems for precision farming. In order to keep pace with modern agriculture in developed countries, developing countries must enter the information age, moving from the present model of traditional agriculture to mechanized agriculture, in order to improve land and labour efficiency and productivity, before they are in a position to reach precision farming system at a high level.

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Définition et mise en œuvre de l'agriculture de précision et des pratiques de gestion intégrée des cultures rizicoles en vue d'une production durable au vingt et unième siècle

L'approche des technologies agricoles de précision varie entre les pays développés et les pays en développement. Dans les pays développés, les agriculteurs utilisent des technologies avancées, y compris les technologies de l'information, pour mieux gérer les intrants agricoles à petite échelle (superficie plus réduite que le champ). Un système d'aménagement localisé peut être réalisé pour améliorer la productivité et l'efficacité et pour réduire les effets sur l'environnement. Il repose sur l'association de cinq technologies: système de géopositionnement par satellite (GPS), télécapteur**,** système d'information géographique (SIG), technologie à taux variable (TTV) et contrôle des rendements.

Les techniques agricoles de précision, relativement récentes, sont progressivement adoptées aux États-Unis d'Amérique, en Europe et en Australie. Le rapport coûts/avantages n**'**est pas encore bien défini, mais le système a été adopté dans nombre de grandes exploitations qui pratiquent des cultures a valeur élevée. Les capacités du système ainsi que la collecte et la gestion d'informations doivent être encore améliorées.

Dans les pays en développement, les agriculteurs peuvent recourir aux technologies de précision en utilisant leurs propres moyens et leurs propres connaissances pour accroître les revenus économiques et réduire les risques pour l'environnement, à partir des recommandations des vulgarisateurs. Ils sont encouragés à utiliser un système de gestion intégrée des cultures – similaire au RiceCheck australien – pour réduire les différences de rendement ainsi que la pauvreté rurale. Un système de gestion intégrée des cultures est un outil de production qui aide les agriculteurs à utiliser les quantités nécessaires d'intrants agricoles au moment voulu, ce qui permet de réduire les coûts de production et d'augmenter les bénéfices. Le morcellement des terres est très fréquent dans la production de riz en Asie et en Afrique; de ce fait il y a peu de variation d'un champ à l'autre et le système d'aménagement localisé dans le cadre de la gestion intégrée des cultures n'est pas fondamental pour les petits agriculteurs qui ne disposent souvent que de quelques hectares par famille.

Cela dit, sur une base régionale, les administrateurs et les chercheurs agricoles devraient envisager d'utiliser les technologies modernes de précision (coordonnées GPS, indications géographiques et cartes de rendement): pour mieux cibler les recommandations destinées à des endroits précis dans la région; pour déceler des attaques de ravageurs, les zones de sécheresse et les endroits à risque d'inondations soudaines; ainsi que pour la gestion appropriée des ressources. Il est important que les petits agriculteurs puissent bénéficier des technologies modernes de l'information.

El concepto y aplicación de la agricultura de precisión y el sistema integrado de gestión de cultivos de arroz para la producción sostenible en el siglo XXI

La interpretación de la agricultura de precisión varía entre los países desarrollados y los países en desarrollo. Los agricultores de los países desarrollados se benefician de tecnologías avanzadas, como por ejemplo las tecnologías de la información para gestionar mejor los insumos agrícolas en menor escala que el campo en su totalidad. Para mejorar la productividad y la eficacia y reducir los efectos ambientales puede llevarse a cabo la ordenación específica para cada lugar, que se basa en la incorporación de cinco tecnologías: sistema de posicionamiento global (GPS), sensor a distancia, sistema de información geográfica (GIS), tecnología de aplicación variable de insumos (VRT) y seguimiento del rendimiento.

La agricultura de precisión es relativamente nueva y se está adoptando poco a poco en los Estados Unidos de América, Europa y Australia. Aunque sigue poniéndose en duda la relación entre costos y beneficios, muchas explotaciones a gran escala con cultivos de alto valor ya han adoptado el sistema. Es necesario seguir mejorando las técnicas del sistema y la recopilación y gestión de la información.

En los países en desarrollo, los agricultores pueden aplicar el sistema de agricultura de precisión utilizando sus propios medios y conocimientos para aumentar las ganancias económicas y reducir los riesgos ambientales, basándose en las recomendaciones de los trabajadores de extensión. Se les alienta a utilizar el sistema integrado de gestión de cultivos, parecido al sistema RiceCheck australiano, para reducir las brechas de rendimientos, así como la pobreza rural. El sistema integrado de gestión de cultivos es un instrumento de producción integrada, que ayuda a los pequeños agricultores a aplicar insumos agrícolas en las cantidades adecuadas y en el momento oportuno, reduciendo así los costos de producción y mejorando los beneficios. La fragmentación de las tierras es muy común en la producción del arroz en Asia y África, por lo que apenas hay variabilidad en el campo y el enfoque específico para cada lugar del marco del sistema integrado de gestión de cultivos no resulta indispensable para los pequeños agricultores que no suelen tener más de unas pocas hectáreas por familia.

Sin embargo, a nivel regional, los administradores e investigadores agrícolas deberían tener en consideración la utilización de tecnologías modernas de agricultura de precisión, como por ejemplo GPS, GIS y mapas de rendimiento, a fin de formular de manera más acertada recomendaciones relativas a lugares específicos en la región, detectar la presencia de plagas, sequía y puntos de crecidas repentinas, y gestionar de forma adecuada los recursos. Es importante que los pequeños agricultores obtengan los beneficios de la era de las tecnologías de la información.

The system of rice intensification: using alternative cultural practices to increase rice production and profitability from existing yield potentials

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Although the system of rice intensification (SRI) is controversial in some circles (Surridge, 2004), it is gaining acceptance and beginning to spread around the rice-growing world. Age-old cultural practices, such as transplanting rather mature seedlings densely in paddies that are kept continuously inundated, are demonstrable constraints to productivity; the increased application of synthetic fertilizers and agrochemicals is not economically viable for many farmers and it is also environmentally undesirable and unsustainable.

At the International Rice Conference convened by FAO for the International Year of Rice in 2004, IRRI's former director-general, Dr Ronald Cantrell, gave the following objectives for the rice sector to enable it to better meet the needs of both people and countries in the twenty-first century (Cantrell and Hettel, 2004):

- Increased land productivity
- Greater water productivity
- Accessibility for the poor
- Environmental friendliness
- Increased pest and disease resistance
- Increased tolerance of abiotic stresses
- Higher rice quality
- Increased profitability

These eight goals can be advanced through the use of insights and methods that have been synthesized into what is now called the system of rice intensification (SRI).

Until 6 years ago, this system was known and practised only in Madagascar, the country where it was developed over 20 years ago (Laulanié, 1993). Today, its benefits have been demonstrated in at least 24 countries in Asia, Africa and Latin America, for example:

- In Cambodia, only 28 farmers were willing to try the new methods in 2000 when the NGO (non-governmental organization), Cambodian Center for Study and Development in Agriculture (CEDAC), first presented SRI to dozens of villages. By 2005, the number of SRI users had reached between 40 000 and 50 000 (MAFF, 2005). The Government of Cambodia has made SRI a key part of the agricultural sector strategy in its national development plan for 2006-10.
- In India, Andhra Pradesh state, where the first on-farm comparison trials were made in 2003, results across all 22 districts demonstrated a yield advantage of 2.5 tonnes/ha over best farmer practices. Within 3 years, the area under SRI in the state had reached more than 40 000 ha (ANGRAU, 2006). The Government of India has recommended the new methods to Indian rice farmers "wherever feasible" (press release, 31 May 2005).
- In eastern Indonesia, with the intervention of a management team from the consulting firm, Nippon Koei, farmers did 1 849 on-farm trials between 2003 and 2005 over a total area of 1 363 ha. Average SRI yields were 84 percent higher than current best farmer practices and used about 40 percent less water (Sato, 2006). With fertilizer use reduced by 50 percent, farmers' overall production costs were lowered by 25 percent; their net income from rice production could, therefore, increase fivefold.
- In Africa and Latin America, SRI has been slower to spread, but its advantages have nevertheless been seen in no fewer than ten countries outside Asia. For example, a farmers' cooperative in northwest Zambia – where rice yields are less than half the world average and where food aid is often needed – applied SRI in the last season and achieved rice yields of 6.144 tonnes/ha (dried weight) (Ngimbu,

2006). In Madagascar, over 200 000 farmers are currently using SRI methods, with yields as high as 17 tonnes/ha (the Hon. Harison E. Randriarimanana, Minister of Agriculture, Livestock and Fisheries, personal comment, 31 March 2006).

Since SRI productivity is driven more by biological agents and endogenous soil processes (enhanced by alternative management practices) than by external inputs, there is considerable variation in results, from place to place and year to year. Success cannot always be guaranteed – any more than with other agricultural methods. Nevertheless, the accumulating evidence of SRI's positive effects should make the system of interest to farmers, researchers and policy-makers alike.

THE NEED FOR A PARADIGM SHIFT

The Green Revolution was successful in increasing rice and other grain production in the latter part of the twentieth century, but momentum was lost during the last decade. The Green Revolution paradigm was based on two complementary strategies:

- Change the genetic potential of crop plants, in particular making crops more responsive to the application of fertilizer and other exogenous inputs.
- Increase the application of such inputs – utilizing water, fertilizer and insecticides and other biocides to obtain higher yields.

These efforts resulted in greater production in many countries around the world. The success was achieved, however, at a cost – environmental as well as economic. Of particular concern is the heavy dependence on inorganic N for raising rice output. In China, for example, over-application of N fertilizers has become a serious problem, with farmers responding to diminishing returns by applying larger and larger quantities of N fertilizer. Forty years ago, application of 1 kg of N could yield 15 to 20 kg of additional rice. Now a mere extra 5 kg of rice are obtained from the addition of 1 kg of N (Peng *et al.*, 2004), and this figure is still decreasing. In places where N fertilizer application rates now exceed 500 kg/ha per year, nitrate levels in the groundwater are reaching 300 ppm of dissolved nitrate (S. Peng, personal communication, citing studies by Jerry Hatfield, United States Department of Agriculture [USDA]). According to the United States Environmental Protection Agency, 50 ppm is the highest level deemed acceptable in drinking water supplies, and even 10 ppm can cause serious health problems for newborns. Thus, the use – and especially the overuse – of N fertilizer needs to be curtailed in many areas.

Cassman *et al.* (1998) estimated that, given the declining marginal productivity of N fertilizer, to achieve the 60 percent increase in rice production that the world needs by 2030, it will be necessary to triple N fertilizer applications. This is likely to be unacceptable environmentally and unfeasible economically. Moreover, such increases in fertilizer use would have adverse impacts on soil and water quality and would increase greenhouse gas emissions from rice paddies if continuously flooded (Liesack, Schnell and Revsbach, 2000). It is, therefore, essential to explore ways of mobilizing more of the N that plants need through cheaper and ecologically more benign biological processes.

The land and water resources for rice production are diminishing. In Asia, the increase in urbanization and industrialization has reduced the water for agricultural production in general and for rice production in particular (Barker *et al.*, 1999). Elsewhere – for example, in Australia, Egypt, Portugal and Spain – inadequate water supply is the main factor limiting the cultivation of rice (Nguyen and Ferrero, 2006). In some of the most intensively-cropped areas in China and India, where groundwater is used for irrigation, water tables have been falling at a rate of 1 m per year or more. Darwin *et al.* (2005) estimated that the amount of land for rice, maize, sugar cane and rubber in tropical areas would decline by 18 to 51 percent in the next century as a consequence of global warming. Thus, productivity gains from the remaining land and water resources are increasingly urgent.

Global rice production in 2005 was just sufficient to meet the world demand for rice, and it is projected that production in 2006 will satisfy effective demand (Calpe, 2006). This does not take into consideration, however, the more than 850 million people suffering from hunger and malnutrition associated with poverty. Given the continuing growth of the world population, the need for global production is projected at 771 million tonnes by 2030, and there will be a smaller resource base (FAO, 2003). Sustainable increases in rice production are a key element in meeting Millennium Development Goal 1, to reduce hunger and poverty in the world. Reducing the agricultural demand for irrigation water (in particular, for rice) is crucial for sustainable production in the future.

Helping plants develop better root systems is a biological strategy for addressing water scarcity; it is less costly than other solutions which continue to increase the water supplied for rice production.

UNDERSTANDING THE SYSTEM OF RICE INTENSIFICATION

The system of rice intensification is a set of insights and principles applied through certain management practices that promote more productive phenotypes from existing genotypes of rice, whether improved or local varieties. This is accomplished by:

- inducing greater root growth; and
- nurturing more abundant and diverse populations of soil biota which provide many benefits for plants (Wardle, 2002).

Altering the management of rice plants' soil, water and nutrients is a low-cost way of enhancing plant root growth and the activity of soil organisms. Non-SRI practices can be detrimental in various ways:

- Flooding of rice plants has been practised for centuries, even millennia. It constrains growth, functioning and survival of the roots. Up to three-quarters of the rice roots degenerate by the start of the plant's reproductive period (Kar *et al*., 1974).
- Crowding rice plants in dense hills or close spacing of hills results in the growth potential of the canopies and root systems being inhibited. The "edge effect" – i.e. the more vigorous and productive growth of widely-spaced plants – is thus limited to the borders of rice fields.
- Heavy application of fertilizers and agrochemicals can have adverse impacts on the soil biota, which provide numerous services to plants: N fixation, N cycling, P solubilization, protection against diseases and abiotic stresses, and induced systemic resistance, for example (Tan, Hurek and Reinhold-Hurek, 2002; Doebbelaere, Vanderleyden and Okon, 2003; Randriamiharisoa, Barison and Uphoff, 2006).

SRI methods create above-ground and below-ground environments that are more favourable for the rice plant's growth (Stoop, Uphoff and Kassam, 2002; Randriamiharisoa, Barison and Uphoff, 2006). SRI involves transplanting young seedlings (<15 days, preferably 8-12 days), singly (not in clumps), very carefully and gently, with optimal wider spacing (starting at 25×25 cm and increasing whenever better soil fertility permits). Irrigated paddy soils are kept moist but are not continuously saturated, maintaining mostly aerobic soil conditions, either by daily applications of small amounts of water or by alternate wetting and drying. For best results, weed control is done with a rotary hoe several times during the vegetative growth phase before the canopy closes, aerating the soil as well as removing weeds. Organic fertilization (compost, manure, mulch etc.) is utilized to the greatest extent possible, although synthetic fertilizers can be used if insufficient biomass is available. Although SRI was developed for irrigated rice production, a new variant is rainfed SRI, where SRI concepts and methods are adapted to upland circumstances. Yields of 6 to 8 tonnes/ha have been reached with such adaptations in northern Myanmar, southern Philippines and eastern India (Kabir, 2006; Gasparillo *et al*., 2003; Sinha and Talati, 2005).

RESULTS OF SRI EVALUATION

Researchers in different countries and from various institutions conclude, following years of analysis, that SRI methods offer multiple major benefits. Research has been extensive and the list below is far from exhaustive:

- **China:**
  - Tao, Wang and Min (2002), Zhu *et al*.(2002) and Zhu (2006) (China National Rice Research Institute)
  - Yuan (2002) (China National Hybrid Rice Research and Development Center)
  - Zheng *et al*. (2004) (Sichuan Academy of Agricultural Sciences)
  - Wang *et al*. (2002) (Nanjing Agricultural University in China)

- **Indonesia:**
  - Gani *et al*. (2002) (Indonesian Agency for Agricultural Research and Development)

- **India:**
  - Satyanarayana, Thiyayarajan and Uphoff (2006) (presenting data from more than 1 600 on-farm trials supervised by the agricultural universities in Andhra Pradesh and Tamil Nadu states)
  - Subbiah, Kumar and Bentur (2006) (Indian Council of Agricultural Research)

- **Japan:**
  – Horie *et al.* (2005) (Kyoto University)

The scientific basis for acceptance of SRI methods is thus increasingly well understood, although research still remains to be done: SRI is a work in progress.

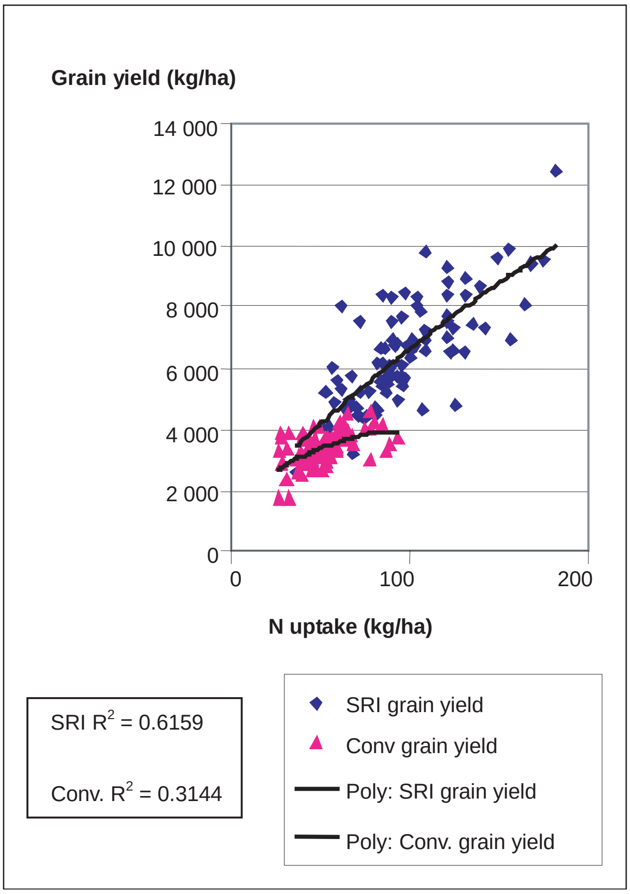
The results reported by the M.S. Swaminathan Research Foundation (Table 1) are reasonably representative of those obtained in farmers' fields using alternative methods. Trials showed SRI yielding between 7.5 and 9.75 tonnes/ha, compared to 4.056 tonnes/ha – a yield increase of between 87 and 144 percent. Taking into consideration the reduced cost of inputs and decrease in water consumption, the returns to farmers' resource investment was even greater.

Figure 1 shows how plants grown with SRI methods are better able to take up nutrients and convert them into grain yield. This relationship, as well as many others, was evaluated by Barison (2002) using the QUEFTS model (Janssen *et al*., 1990). The analysis revealed how yield could double with SRI methods when the same farms and same farmers were involved. The same relationships were seen in the measurement of P and K.

The analysis of rice plant roots revealed that SRI plants have better and deeper root growth (Table 2). Although they have less root density in the top soil layer (0-5 cm below the surface) compared with rice plants grown using conventional methods, they have more root density in lower soil layers. Visual comparison of SRI and conventional rice plants growing under comparable soil conditions confirms what Barison measured.

Planting fewer and younger seedlings combined with a reduction in water applications may seem risky. On the contrary: when SRI methods are used as recommended, the result is positive, due in part to the larger, deeper root systems induced by SRI practices and which offer rice plants protection against abiotic stresses. Evaluation by the International Water Management Institute (IWMI) (Namara, Weligamage and Barker, 2004) and the German

FIGURE 1
Regression relationships between N uptake and grain yield for SRI and conventional methods



Source: Barison, 2002.

TABLE 1
Comparison of SRI and conventional methods of paddy cultivation

Parameters	SRI farmer I	SRI farmer II	Conventional practice
Total no. tillers	26	45	18
No. productive tillers	24	38	13
No. grains/plant	230	275	220
Yield (*kg/ha*)	7 500	9 750	4 056
Labour for planting		40	25
Labour for weeding		30	25
Labour for harvesting		20	20
Seed rate (*kg/ha*)	5	6	30

Source: MSSRF, 2004.

TABLE 2
Root length density (cm/cm³) under SRI, SRA and farmer practices

Treatments	Soil layers (*cm*)					
	0-5	5-10	10-20	20-30	30-40	40-50
SRI with compost	3.65	0.75	0.61	0.33	0.30	0.23
SRI without compost	3.33	0.71	0.57	0.32	0.25	0.20
SRA with NPK and urea	3.73	0.99	0.65	0.34	0.18	0.09
SRA without fertilization	3.24	0.85	0.55	0.31	0.15	0.07
Farmer practice	4.11	1.28	1.19	0.36	0.13	0.06

Notes:
SRA = *Système de riziculture ameliorée* (system of improved rice cultivation), which is the modern set of practices recommended by government researchers.
Measurements from replicated on-station trials, Beforona, Madagascar (Barison, 2002).

TABLE 3
Interaction of management practices, endophytic Azospirillum and yield in clay soil plots

Practice	Yield (*tonnes/ha*)	Azospirillum count in root tissue	Comments
Conventional methods, no nutrient amendments	1.8	65×10^3	
SRI, no nutrient amendments	6.1	11×10^5	
SRI, NPK fertilizer	9.0	45×10^4	Yield increase of 50% with reduction of 60% in Azospirillum count indicates that plants are relying on inorganic N sources to achieve yield increase
SRI, compost	10.5	14×10^5	Highest yield with an Azospirillum count 3 times more than with NPK

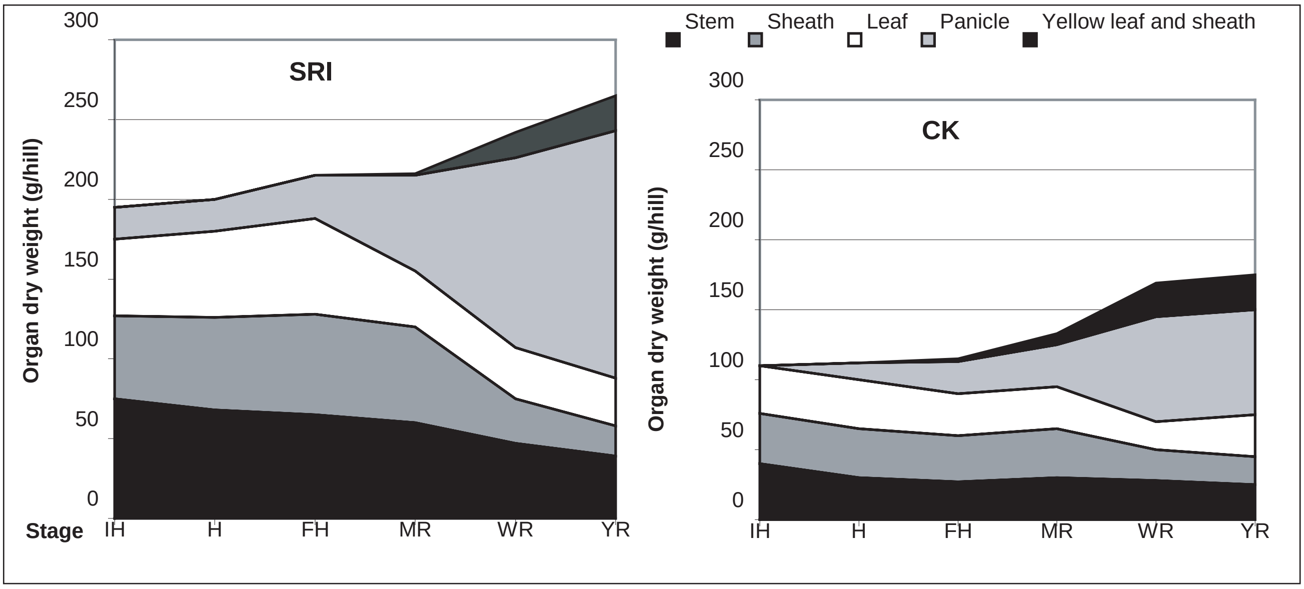
Agency for Technical Cooperation (GTZ) (Anthofer, 2004) show that SRI methods reduce farmers' risk of economic loss.

Further research is required to ascertain to what extent soil organisms contribute to improved rice plant performance when SRI is adopted. Nevertheless, changes in the Azospirillum populations living inside rice roots and associated with SRI practices were evaluated in replica trials (Andriankaja, 2001) and reported by Randriamiharisoa (2002). The changes in yield and microbial populations in response to different management practices are shown in Table 3.

Greater root growth with SRI methods may be stimulated and supported by the production of phytohormones by aerobic bacteria and fungi that live in the soil and on and inside the roots. These organisms are known to produce auxins, cytokinins and other plant growth-promoting compounds in the rhizosphere (Frankenberger and Arshad, 1995). Recent published research from China has shown that soil rhizobia which enter the rice plant through its roots – and then migrate to the stem and leaves – contribute to significant increases in leaf chlorophyll, photosynthesis and crop yield (Feng *et al*., 2005). Plant science thus needs to expand to include microbiology as an integral discipline, not an allied field of study.

USDA research has also shown how DNA expression in leaf cells – specifically genes that affect senescence and the production of chitins that confer certain disease resistance – are affected by changes in the way that plants are managed together with the soil, water and nutrients that they utilize (Kumar *et al*., 2004; Mattoo and Abdul-Baki, 2006). The cytokinin, which is produced in the roots, affects canopy growth, while auxins synthesized in the canopy reciprocally affect root growth and performance (Oborny, 2004). Rates of leaf photosynthesis, for example, are affected by what is going on in the soil, and direct connections exist between root and soil conditions and genetic functioning in the leaves. Tao (2004) reported that SRI plants have better growth rates as indicated by the relative changes in dry weight of different rice plant organs (stem, sheath, leaf and panicle), as well as senescence in the leaf and sheath (in yellow), as rice plants move through their different stages of growth (Figure 2).

FIGURE 2
Relative and absolute comparisons of SRI and control (CK) plants of same variety



Source: Tao, 2004.

RESULTS OF SRI UTILIZATION AND POTENTIAL CONSTRAINTS

The simplest yardstick for measuring and comparing crop performance is yield, expressed in terms of output per unit of land, as this resource has often been the limiting factor of production. But yield by itself is not an adequate criterion of assessment, and it is not the most important to farmers. Total factor productivity is more meaningful; in addition to kg of rice produced per unit of land, it is also important to consider output per day or hour of labour, per cubic metre of water, and per unit of capital.

Table 4 summarizes the analysis of the results of 4 800 comparison trials in diverse locations in eight countries: Bangladesh, Cambodia, China, India, Indonesia, Nepal, Sri Lanka and Viet Nam (Uphoff, 2006).

Not all SRI practices were used (or used as recommended) in all evaluations; there is, therefore, potential for improvement if the methods are applied fully and correctly, as seen in factorial trials (Randriamiharisoa and Uphoff, 2002).

Labour requirements

The data from India (Table 1) show that labour requirements for the three main operations increased by 38 percent with SRI. However, the returns (measured in kg of rice per day) also increased greatly – by 73 percent. The data are from the first season of SRI practice. SRI labour requirements typically diminish as farmers become familiar with the methods; eventually, SRI can require less labour per ha (Barrett *et al.*, 2004).

A large-scale evaluation of SRI in Cambodia, based on 500 randomly selected farmers (Anthofer, 2004), found SRI to be labour-neutral overall, with new SRI farmers needing more labour and experienced ones less. Farmers interviewed for an evaluation in China, where SRI use in one village had risen from just 7 in 2003 to 398 in 2004, ranked labour-saving as SRI's most attractive feature – more important than increased yield, water-saving or profitability (Li, Xu and Li, 2005).

TABLE 4
Summarized results from 11 comparative evaluations of SRI in 8 countries

Effect of SRI	Impact (%)	Range (%)
Yield increase (*tonnes/ha*)	52	21-105
Reduction in water use	44	24-60
Reduction in production costs	25	2.2-56
Increase in net income (*per ha*)	128	59-412

Source: Uphoff, 2006.

Water management

The most objective and serious limitation encountered to date with SRI is water control. For best results, farmers need reliable control over water during crop establishment. However, this is not always possible in monsoon areas, where SRI may, as a consequence, be unsuitable or, if applied, yields will be lower than elsewhere. Water control can be achieved in many places through investment in physical infrastructure or through farmer organization and cooperation. A reduction of 25 to 50 percent in on-farm water use produces substantial benefits if aggregated, but SRI has not been adopted on a scale wide or complete enough to know how much net benefit is attainable from reduced irrigation off-takes. WWF-India (World Wide Fund for Nature – India) has begun supporting SRI adoption because of its implications for the rice sector's water requirements (Murthy and Punna Rao, 2006).

Crop protection

With the cultivation of larger plants and the production of more grain, the challenge of crop protection increases. SRI farmers tend not to report losses through pests and diseases – which may be accounted for by the theory of trophobiosis (Chabousson, 2004). In some locations, measures may be necessary against nematodes, golden snails or other pests, but the most common evaluation is that SRI methods reduce crop losses caused by pests and disease. There are numerous reports by farmers stating that SRI rice does not need chemical protection.

Grain quality

Another benefit of SRI is improved grain quality. This may be due to the plants' larger, deeper root systems capable of accessing a greater variety and increased volume of nutrients, particularly micronutrients. Conventional root systems remain shallow and die back under hypoxic soil conditions. The data in Table 5 indicate that chalkiness is significantly lower in SRI-grown rice, which could justify a higher price. Even more important, from an economic point of view, is the higher out-turn of milled rice from SRI paddy (rough rice). SRI paddy usually has fewer unfilled grains, and thus less chaff; it tends to be more resistant to shattering, resulting in fewer broken grains. Reports by farmers and millers from India, Sri Lanka and Cuba and research carried out in China (Jun, 2004) show that the milling out-turn from SRI paddy is approximately 15 percent higher.

It appears that the reduction in the application of synthetic fertilizers and crop-protection chemicals results in enhanced soil and water quality and improved human health. Furthermore, the denser grains obtained with SRI due to the larger, better functioning root systems, are likely to have higher levels of micronutrients. Further research and evaluation is required in both these areas.

CONCLUSIONS

SRI is a methodology for human resource development, not a technology to be transferred (Laulanié, 2003). Farmers should be involved in experimentation with the new methods and practices adapted to suit local conditions; farmers' knowledge and confidence are thus built up through their experience of using SRI. Farmer education is a benefit, not just a cost. While SRI can be promoted in a top-down manner, dissemination in participatory ways is preferable so as to build up human capabilities for decision-making and management. SRI is simple to learn for anyone who already knows how to grow rice: farmer-to-farmer interaction is the most effective way to spread SRI. The farmer field school methodology promoted by FAO is particularly suitable for SRI diffusion (Kabir, 2006).

Rather than replace the Green Revolution, SRI offers rice farmers alternative methods for increasing production (Uphoff, 2003). SRI is particularly suited to farmers who:

- have difficulty affording the inputs required by Green Revolution technology;
- face water shortages; or
- want to avoid risks such as lodging, drought or cold damage, caused by adverse climates.

TABLE 5
Measured differences in grain quality with SRI and conventional methods, June 2004

Characteristic	SRI (3 spacings)	Conventional (2 spacings)	Average difference
Chalky kernels (%)	23.62 - 32.47	39.89 - 41.07	- 30.7
General chalkiness (%)	1.02 - 4.04	6.74 - 7.17	- 65.7
Milled rice out-turn (%)	53.58 - 54.51	41.54 - 51.46	+ 16.1
Head milled rice (%)	41.81 - 50.84	38.87 - 39.99	+ 17.5

Water control is the most objective and serious limitation to SRI encountered to date. For best results, farmers should have reliable control over water during crop establishment. In monsoon areas, this may not be possible: SRI may not be suitable or, if applied, yields will be less than otherwise obtainable. Water control can be obtained in many places where it is absent through investment in physical infrastructure or through farmer organization and cooperation. SRI creates incentives for organization and can assure a good economic return from investment. However, in many cases, lack of water control is not necessarily a constraint to SRI adoption. Optimal conditions for SRI adoption include irrigation with groundwater, because farmers have control over their water supply and there are incentives for reducing water application.

At present, SRI raises more questions than it answers. This should be regarded as good news by researchers, as SRI creates a large and promising research agenda.

Since SRI methods have been derived inductively, from observation and by trial-and-error, SRI should be amenable to further refinement and development. Also, it is quite possible that SRI will encounter certain problems or limitations in the future, which researchers could identify and develop counter-measures for. The basic mechanisms involved in SRI – enhancement of root growth and soil biological communities – might help improve the performance of other crops if better understood. SRI is still at an early stage of both theory and practice.

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Le système d'intensification du riz: utilisation de pratiques de culture différentes pour accroître la production de riz et les profits à partir du potentiel de rendement existant

Le système d'intensification du riz est une méthode qui permet d'obtenir davantage de phénotypes productifs à partir des génotypes du riz existants. Il modifie la gestion des plantes, du sol, de l'eau et des fertilisants sur le terrain avec des effets positifs sur les biotes du sol.

En transplantant les jeunes plants un à un, plus rapidement, avec plus de soin, en laissant davantage d'espace et en assurant des applications intermittentes d'eau pour maintenir l'essentiel les conditions aérobiques du sol, on obtient de meilleurs rendements tout en diminuant les quantités de semences et d'eau utilisées. Les revenus nets des agriculteurs augmentent donc du fait des rendements accrus et de la baisse des coûts de production. Accueillis au départ avec une certaine réticence, les avantages du système d'intensification du riz sont maintenant reconnus dans vingt-quatre pays. Il convient en outre de noter que des besoins accrus en main-d'œuvre ont été nécessaires au départ mais qu'il est maintenant possible de réaliser des économies dans ce secteur.

Le système d'intensification du riz représente une mutation profonde, l'attention étant axée sur le développement d'un système radiculaire important et vigoureux ainsi que sur l'abondance, la diversité et l'activité des organismes contenus dans le sol.

L'article fait état des résultats empiriques obtenus dans un certain nombre de pays permettant de mieux comprendre comment accroître la productivité du riz en respectant l'environnement et en obtenant des résultats positifs du point de vue socio-économique.

El sistema de intensificación del arroz: utilizar prácticas de cultivo alternativas para aumentar la producción y rentabilidad del arroz a partir de los potenciales de rendimiento existentes

El sistema de intensificación del arroz (SRI) es una metodología encaminada a producir fenotipos más productivos a partir de genotipos de arroz existentes. Cambia la forma en que las plantas, el suelo, el agua y los nutrientes se gestionan en el campo, con efectos positivos sobre la biota del suelo.

Al trasplantar plantones más jóvenes, individualmente, con mayor rapidez y cuidado, con un espaciamiento más amplio y con aplicaciones intermitentes de agua para mantener unas condiciones del suelo principalmente aeróbicas, aumentan los rendimientos y se reduce la necesidad de insumos de agua y semillas. Los ingresos netos de los agricultores se incrementan debido no sólo a la obtención de rendimientos más elevados, sino también a la reducción de los costos de producción. Aunque inicialmente su aceptación resultó lenta, las ventajas de este sistema se han demostrado ya en 24 países. Además, tras una acentuación inicial de la intensidad del trabajo, se está consiguiendo ahora el ahorro de mano de obra.

El SRI representa un cambio de paradigma que atiende al desarrollo de sistemas radiculares amplios y firmes, así como a la abundancia, diversidad y actividad de los organismos del suelo.

En este artículo se facilitan datos sobre los resultados empíricos de una serie de países que ayudan a entender mejor la manera de aumentar la productividad de los factores en la producción del arroz de una forma inocua para el medio ambiente y beneficiosa desde el punto de vista socioeconómico.

Weedy rice problems and solutions for its management

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Rice areas in several countries in the Western Hemisphere are seriously affected by the presence of several weeds. The most troublesome weeds in rice are species of the genus *Echinochloa*. However, there is an increase worldwide in problems with weedy rice, which reduces crop yields and affects quality more than *Echinochloa crus-galli*. Yield reduction can even be as much as 80 percent (Smith, 1988). Weedy rice is the same species as cultivated rice (i.e. it usually has the same genome), but it behaves differently. It normally grows faster; makes better use of the available N; produces more tillers, panicles and biomass in general; shatters earlier; has better resistance to adverse dry conditions; and possesses longer dormancy in soil (Cohn 2002; Gu, Chen and Foley, 2003).

The problem of weedy rice has grown with the increase in direct-seeded rice in several countries, including parts of Southeast and South Asia. Given the importance of the problem, FAO conducted activities to assist developing countries to reduce weedy rice infestations in rice. FAO began with the organization of a global workshop on the subject, held in Varadero, Cuba (FAO, 1999), with the participation of specialists from 17 countries. The workshop concluded that high weedy/red rice incidence in many rice-producing countries is due to the increase in use of unclean rice seeds, monocropping and wrong cultural practices during the crop cycle. These conclusions point to the need to adopt an integrated management approach, where sources of weedy rice are reduced using several management strategies.

Strategies for the control of weedy rice are diverse and their implementation depends on the specific site conditions. However, any control measure should aim to reduce the weedy/red rice seed bank in soil in the medium or long term.

Following the workshop, various countries from Latin America requested FAO's technical assistance for the implementation of a project aimed at the control of weedy rice.

RESULTS OF FAO WEEDY RICE PROJECT IN CENTRAL AMERICA AND THE CARIBBEAN

The project consisted of participatory training for farmers through the implementation of two farmer field schools (FFS), where farmers learned elements of the ecology of weedy rice and its control. Six countries were involved:

- **Colombia.** Rice is grown on 320 000 ha. The crop is normally grown twice a year and monocropping is a normal practice. Use of uncertified rice seeds of low quality is common in areas of poor farmers.
- **Costa Rica.** The rice area is approximately 40 000 ha distributed in five regions: Chorotega, Brunca, North Huetar, Central Pacific and Atlantic. The area infested by weedy rice is almost 19 500 ha. The major weedy rice species are *Oryza sativa* L. and *O. latifolia* Desv. (known locally as "arrozón"). Incidence is greatest in fields where rice is cropped twice.
- **Cuba.** Rice is the country's major staple, grown in an area of less than 200 000 ha, of which 35 percent is severely affected by weedy rice. In heavily infested areas, yield losses account for up to 89 percent. This problem is aggravated by the reduced production of certified rice seed or the use of bad quality seeds contaminated with weedy rice seeds.
- **Nicaragua.** Weedy rice is present in all rice-producing areas of the country with infestation at more than 80 panicles/m^2. The main weedy rice species are *Oryza sativa* and *O. latifolia* with infestation of up to 40 percent in rice fields. Farmers do not use certified seeds and no specific method is practised to control this weed.
- **Panama.** Rice is grown on more than 75 000 ha, mainly in the provinces of Chiriquí (54%), Coclé (14%), Panama (Chepo) (11%) and Veraguas (9%). Rice yields are not high due to the use of uncertified seeds with low germination level, and because of high pest incidence, including the problem of weedy rice.

- **Venezuela (Bolivarian Republic of).** The rice area is approximately 140 000 ha, predominantly in the states of Portuguesa, Guárico, Cojedes and Barinas. Weedy rice is one of the major constraints to rice production, with 88 percent of the crop area infested by weedy rice, sometimes with a stand of 17 or 18 plants/m^2. The main species of weedy rice in Venezuela (Bolivarian Republic of) are *Oryza sativa* L., *O. rufipogon* Griff. and *O. latifolia* Desv.

The project included the education of pilot groups of farmers on weedy rice biology and control strategies. For this purpose, FFS were implemented and farmers met every 2 weeks to discuss the results of their observations in the field. Training covered studies of viable weed seed bank in soil using the methodology proposed by Forcella, Webster and Cardinia (2003), collection of weedy rice biotypes and their germination. Farmers were helped to understand the sources of weedy rice infestation and to design management procedures. The importance of using clean rice seeds free of weedy rice seeds was stressed. This strategy, together with pre-planting control of the weed, was the management approach adopted in most places.

Pre-planting control

In some areas, the pre-planting method consisted of land preparation in dry soils, followed by fast irrigation, puddling, draining the field for the emergence of new weed flushes, application of glyphosate, flooding again and rice seeding over a slight water layer. In other areas, land preparation began with puddling, draining the field, glyphosate application, flooding and seeding as above. The control of weed flushes in some areas was conducted mechanically after drainage. In Nicaragua, this method increased yields by 25 percent and improved the quality of the produce.

In Venezuela (Bolivarian Republic of), after the harvest, crop residues in infested fields were burnt – an operation which encouraged germination of weedy rice seeds remaining in the soil surface. Soil moisture was maintained for a period of 85 days, until infestation reached a level of 130 plants/m^2. Land preparation was then conducted followed by flooding and drainage; it was left for another 15 days until there was a new weed flush; the same operation was then repeated for another flush, after which the area was flooded over the weed stand and herbicide (oxadiargyl at a rate of 1.15 litres/ha) was applied and kept for 8 days. The field was drained and 2 days later pre-germinated rice seeds were planted.

Other control methods

The leguminous plant *Sesbania rostrata* Brem. has been tested in Cuba for short crop rotation – it successfully smothered weedy rice.

In all FFS, emphasis was placed on the importance of roguing – either manually or using glyphosate – shortly before harvest to avoid an increase in weed seed bank in the soil. In Venezuela (Bolivarian Republic of), farmers were well trained in procedures for cleaning the machinery coming from rice fields infested by weedy rice.

IMI RICE TECHNOLOGY

The idea of using herbicide-resistant rice for the successful control of weedy rice is not new. Three companies have been working on this matter:

- Transgenic Liberty Link® rice is being developed by Aventis to resist glufosinate- ammonium herbicide.
- Roundup Ready® rice, developed by Monsanto, tolerates glyphosate.
- IMI rice (known commercially as Clearfield®) was engineered through mutation to tolerate imidazolinone herbicides and is being commercialized by BASF.

IMI rice is not a transgenic crop, and has been adopted for use in several countries, including the United States, Costa Rica, Colombia and Uruguay. It is mutated rice developed by radioactive bombardment of a conventional rice plant – a technology that has been used to achieve short-stature rice varieties (Annou *et al.*, 2001).

In the United States, IMI rice is associated with the use of the imidazolinone herbicide, imazethapyr, an ALS inhibitor. The herbicide is applied after planting at 5 ounces per acre (approx. 0.346 kg/ha) in drill-seeded systems, while in water-seeded fields, seeding flood is put on after the first application of the herbicide, the water pulled off and the seedlings are then allowed to establish. Normally one application of this herbicide (non-selective to rice) is enough. That is why farmers apply twice or even use some mixtures with other herbicides, such as pendimethalin and propanil. This treatment can reduce enormously the stand of weedy rice (Rodd 2004).

However, an outcrossing between IMI herbicide-resistant rice and weedy rice has recently been discovered in Arkansas (Schultz, 2004) – demonstration of the fact that farmers must not abuse herbicide-resistant material. Genetic testing confirmed that weedy rice contains the resistant gene that prevents imazethapyr from damaging rice plants. The resistant hybrids are tall plants with compact, erect and rough leaves. According to extension workers, not planting IMI rice two growing seasons in a row is probably the most important measure to ensure the longevity of this technology.

It is clear that there is no technology that can control 100 percent of any weed population. Normally a low resistant weed population will be selected quickly if the same herbicide is used repeatedly. In addition, the ALS inhibitors are recognized as herbicides with high selection pressure and able to select a resistant weed population in a few years.

One solution to the problem of resistance is to rotate the area with conventional rice or with other crops, but lowland areas for rice are often not suitable for growing any other crop, and the use of conventional rice will depend on the level of imazethapyr residue in the soil.

The technology offers a potential solution to farmers – provided that they use it rationally. The use of more than one crop of IMI rice will be enough to achieve a substantial reduction in weedy rice. Additional reduction of the weed can be achieved using other cultural procedures; but these should not be abused with additional cropping of the IMI cultivar. Crop or rice cultivar rotation has an important role in preserving the usefulness of IMI.

SITUATION OF WEEDY RICE IN ASIA

Until recently, Asia had no problem of weedy rice, due to the fact that transplanted rice was the main planting method. In the United States and most Latin American countries, the situation is different because direct-seeded rice prevails.

With the opening of new factories, people have moved from rural to urban areas, reducing considerably the labour formerly used for planting and weeding. It is for this reason that farmers have been compelled to shift from transplanting to the direct-seeding method.

The area affected varies from country to country. Thailand has more than 2 million ha seriously affected by weedy rice, while more than 500 000 ha are also infested by the weed in the Mekong River Delta in Viet Nam. Malaysia, Sri Lanka and the Philippines have a substantial area affected, as direct-seeded areas are increasing every year. Current agronomic practices will continue to contribute to making weedy rice the most troublesome weed in rice in the twenty-first century.

Different techniques have been adopted in some Asian countries to manage weedy rice infestation. However, these technologies have not been adopted in many parts of developing Asia, where weedy rice has become a perennial problem for various reasons, including absence of technology transfer and appropriate communication technologies, lack of awareness, and poor farmer attitude. The lack of interaction and communication among scientists on environmentally sound and integrated technologies to control weedy rice has resulted in less attention being paid to capacity-building in the sphere of weedy rice management in Asia.

Since rice is the main staple in several Asian countries, there is an urgent need to implement programmes and projects aimed at weedy rice management. The approach adopted in Latin America by the FAO TCP project on weedy rice can be applied in South and Southeast Asia.

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Problèmes liés au riz adventice: solutions proposées

Le riz adventice est le résultat d'une hybridation naturelle entre des variétés cultivées et des variétés sauvages qui a évolué depuis la domestication du riz sauvage. Le riz adventice a été introduit dans de nombreux pays avec des semences de riz importées d'Asie qui ont été ensuite disséminées. Le riz adventice n'a jamais été un véritable problème tant que le riz a été repiqué mais le manque de main-d'œuvre a contraint plusieurs pays à recourir plus fréquemment aux semis directs, et c'est alors que la situation s'est aggravée.

La concurrence du riz adventice peut entraver les rendements, encore plus que le millet à grappe (*Echinochloa crus-galli*), du fait de la production importante de talles et de panicules par plante de la grande quantité de biomasse et de la forte absorption d'azote prélevée dans le sol. Le riz adventice se développe rapidement et devient plus envahissant avec l'application d'engrais. Le riz adventice s'égrène en général avant le riz cultivé, et les grains pénètrent ainsi dans le sol où ils peuvent rester pendant longtemps.

Le riz adventice n'est pas facile à éradiquer en utilisant un seul moyen technique de lutte car il possède le même génome que le riz cultivé. En général le meilleur moyen de lutter contre le riz adventice consiste à utiliser des semences propres et à effectuer un traitement avant les semis, par exemple une préparation de lit de semences, et d'arracher ensuite les graines de riz adventice qui ont germé par un procédé mécanique ou en utilisant un herbicide adapté, avant les semis de riz.

Une question de grande importance pour le secteur du riz est la possibilité d'élaborer des populations de riz adventice résistant aux herbicides notamment en utilisant du riz résistant à l'imacazolinone (IMI ou Clearfield). Il a été scientifiquement prouvé que l'hybridation entre le riz Clearfield et le riz adventice peut se produire et que le taux de croisement varie selon les cultivars. Ces hybrides de riz adventice ont été trouvés en Arkansas. Il s'agit de plantes de grandes dimensions, aux feuilles compactes, droites et rugueuses. Le riz Clearfield permet de réduire considérablement l'infestation de riz adventice au cours d'une campagne, mais il n'est pas recommandé de l'utiliser pendant deux ou trois campagnes successives afin d'éviter la formation d'hybrides résistant aux herbicides.

Problemas relacionados con el arroz maleza y soluciones para su manejo

El arroz maleza es un producto de hibridación natural entre variedades cultivadas y silvestres, que ha ido evolucionando desde la domesticación del arroz silvestre. El arroz maleza se introdujo en muchos países en la semillas de arroz importadas de Asia y posteriormente se distribuyó. Este arroz no constituía realmente un problema en el arroz trasplantado, pero debido a la escasez de mano de obra en varios países y a la adopción más generalizada de la siembra directa, se ha convertido en un problema grave.

El arroz maleza puede reducir los rendimientos del arroz más que el mijo de los arrozales (*Echinochloa crus-galli*), ya que es muy competitivo debido a la alta producción de esquejes y panículas por planta, el elevado volumen de biomasa y la considerable extracción de nitrógeno del suelo. El arroz maleza alcanza mayor tamaño y se vuelve más agresivo cuanto más fertilizante se aplica. Las plantas de arroz maleza suelen desgranar mucho antes que el arroz cultivado, lo que le permite acumular fácilmente su banco de semillas de maleza en el suelo. Asimismo, las semillas pueden aguantar largos períodos en el suelo.

No es fácil luchar contra el arroz maleza con una sola técnica de control, pues se trata de una maleza con el mismo genoma que la variedad cultivada. Normalmente, la forma más conveniente de luchar contra el arroz maleza es mediante la utilización de semillas de arroz elaborado y un tratamiento previo a la plantación, como por ejemplo una preparación de semillero falsa, la eliminación mecánica del arroz maleza germinado o la utilización de un herbicida adecuado antes de la plantación de arroz.

Una cuestión de gran importancia para el sector del arroz es el potencial para desarrollar poblaciones de arroz maleza resistentes a los herbicidas, sobre todo con la utilización de arroz resistente a la imidazolinona (IMI o Clearfield). Las investigaciones han demostrado que puede producirse la hibridación entre el arroz Clearfield y el arroz maleza, y el grado de cruzamiento varía entre los cultivares utilizados. Estos híbridos de arroz maleza se han encontrado en Arkansas y son plantas altas de hojas compactas, rectas y ásperas. Aunque la utilización de la tecnología Clearfield reducirá considerablemente la infestación de arroz maleza en una campaña agrícola, no se recomienda utilizarla en dos o más campañas consecutivas para evitar la presencia de estos híbridos resistentes.

Impacts of integrated nutrient management on sustainable rice production with particular reference to Latin American countries

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Production under irrigation and the highly-favoured upland systems currently accounts for approximately 70 percent of all rice production in Latin American countries. Production has increased from 16 million tonnes of paddy in 1980 to 26 million tonnes in 2005. However, farmers' yields remain far below the potential of the available varieties. This yield gap is the result of numerous deficiencies, in particular inadequate crop nutrition practices and their inefficient use (rice requires large amounts of nitrogen and potassium). Two countries are representative of the overall situation:

- In Brazil, nutrient balance studies are negative for the three primary nutrients (N, P_2O_5, K_2O), in particular for nitrogen.
- In Peru, improved varieties respond to potassium, especially where adequate nitrogen and phosphorus are provided.

Sustainable rice production requires integrated management of all the available nutrient resources. Integrated nutrient management (INM) ensures the maintenance and possible enhancement of soil fertility through balanced and judicious use of mineral fertilizers combined with organic and biological sources. The results are seen in terms of improved nutrient efficiency, increased crop productivity and minimized nutrient losses to the environment. Rice-based cropping systems are ideal for deriving benefits from INM.

This paper aims to give an idea of the work required to close the rice yield gap in LAC (Latin America and the Caribbean), and recommends the establishment of nutrient balances in rice-based cropping systems, in order to assist farmers to understand and adopt precision nutrient input management.

RICE PRODUCTION IN LATIN AMERICAN COUNTRIES

Production increased from approximately 16 million tonnes (paddy) to over 26 million tonnes in Latin American countries between 1980 and 2005, even though the area cultivated with rice decreased from 8.2 to 6.7 million ha (Table 1). The principal factor contributing to increased rice production in the region is the increased role of irrigated rice and the demise of upland rice, particularly in Central America and Brazil. In spite of the advancements in productivity, yields in the irrigated sector are still relatively low, and far below the yield potential of currently available varieties. There has been little improvement in yield in the unfavoured upland sector for numerous years.

Rice production in South America during the last two decades (with the exception of the last 2 years) has seen a rapid decline in the area planted with rice, accompanied by a steady increase in overall production. Yield advancement permits production to continue increasing, despite the removal of large areas from rice cultivation. During the 25-year period from 1980 to 2005, average

TABLE 1
Rice production and area harvested in LAC and the world

	Area harvested (*ha*)			Production (*tonnes*)		
	1980	2002	2005	1980	2002	2005
World	144 665 175	147 700 874	153 511 755	396 871 255	578 011 137	614 654 895
LAC	8 207 132	5 775 004	6 746 722	16 443 588	22 227 167	26 370 717

TABLE 2
Rice yield during the last 25 years in selected South American countries

Country	Yield (*tonnes/ha*)			
	1980-82 [a]	1990-92 [a]	1999-2001 [a]	2005
Argentina	3.53	4.30	5.40	6.34
Bolivia	1.55	1.95	1.75	2.17
Brazil	1.51	2.10	3.11	3.34
Chile	3.02	4.10	4.80	4.67
Colombia	4.29	4.05	4.84	5.26
Ecuador	3.08	3.14	3.50	4.13
Guyana	3.06	3.29	4.00	3.86
Paraguay	1.87	2.57	4.09	3.04
Peru	4.53	5.14	6.53	6.71
Suriname	4.03	3.79	3.83	3.80
Uruguay	5.19	4.66	6.49	6.77
Venezuela	2.85	4.18	5.04	5.00
South America	**1.91**	**2.58**	**4.07**	**4.59**

[a] 3-year averages.
Source: FAOSTAT.

yield in South America increased from 1.9 to 4.59 tonnes/ha. The large decrease in the area of low-yielding upland rice in central Brazil, combined with yield improvement in irrigated rice in southern Brazil, contributed significantly to the rapid increase in average yield in South America (Table 2).

Although increases in national yield are the norm for most South American countries, not all countries are advancing at the same rate. Yield improvement in Bolivia was insignificant during the last 25 years, as a result of the concentration of production in the unstable upland sector. Yield improvement in Ecuador was also slow and the poor progress may be attributed to the lack of investment in irrigation management. National yields in Colombia also grew slowly over the last two decades. In the 1980s, Colombia was the country benefiting most from the introduction of high-yielding, semi-dwarf plant types, recording one of the highest national average yields in South America. However, Colombia failed to keep pace with other countries (in terms of yield improvement) and the average national yield is currently inferior to that of Uruguay, Peru and Argentina.

YIELD GAPS

Production under irrigation and the highly-favoured upland systems currently accounts for approximately 70 percent of all rice production in LAC, and high-yielding genotypes occupy more than 90 percent of these areas. However, farmers' yields remain far below the potential of the available varieties. The average yield of irrigated rice is approximately 5 tonnes/ha, but there is high variability between and within production zones. Even within a relatively homogenous area with the same variety, farm yields are highly variable. In many production zones, progressive farmers routinely obtain yields of 7 tonnes/ha.

In late 1999 and early 2000, FAO commissioned a study to explain the discrepancy between farmers' yields and readily obtainable yield (Pulver, Tran and Nguyen, 2000). The difference between readily obtainable yield and average farm yield is referred to as the "yield gap". The study reported that the yield gap in 12 major rice-producing countries ranges from 1 to 3 tonnes/ha and averages 1.3 tonnes/ha. The yield gap is apparent in all irrigated rice production areas.

The yield gap in irrigated rice is the result of numerous deficiencies, in particular inadequate crop management practices which fail to allow high-yielding genotypes to express their yield potential. The yield gap is most striking in countries where new, high-yielding varieties are planted.

MINERAL FERTILIZER USE AND YIELD GAPS

Inadequate and inefficient use of mineral fertilizers is one of the main reasons for the prevalent yield gaps. Table 3 gives the mineral fertilizer use in LAC. Total fertilizer use in 2002 was 13.2 million tonnes in LAC, compared to 141.5 million tonnes in the world (9.3 percent). Brazil accounted for 58 percent of fertilizers used in LAC in the same year.

NUTRIENT BALANCE IN LAC

Brazil

Agriculture in Brazil results in the removal from the soil of a substantial quantity of nutrients that should be replenished by fertilization, especially in the case of nitrogen. In the long term, this situation can become detrimental to the sustainability of agriculture. In the work of Yamada and Lopes (1999) and in the data for 2002 (Table 4), the input of nutrients is based on mineral fertilizers alone; no account is taken for manure and/or nitrogen fixation in cover crops in crop rotation.

Effect of potassium and magnesium on rice grain yield in coastal Peru

With its favourable sunny climate, coastal Peru has the potential for high rice yields. Yields are higher than in the surrounding countries due to substantial nitrogen use. However, a great deal of yield potential is lost because

TABLE 3

Mineral fertilizer use in LAC (*'000 tonnes*)

Country	Nitrogen			Phosphate			Potash		
	1980	1990	2002	1980	1990	2002	1980	1990	2002
Argentina	62.6	101.4	432.6	44.1	51.5	283.3	8.7	12.6	23.5
Bolivia	1.4	2.3	6.1	0.7	2.5	6.6	0.7	0.3	0.9
Brazil	905.4	796.6	1 816.0	1 988.4	1 201.6	2 807.0	1 306.5	1 209.6	3 059.0
Chile	50.8	164.0	210.0	68.8	113.7	170.0	13.0	28.8	75.0
Colombia	151.2	311.8	335.4	81.1	126.7	135.9	80.0	163.8	220.2
Ecuador	40.7	39.4	134.3	14.3	9.0	38.4	17.5	19.6	56.7
Guyana	4.2	8.0	14.4	1.3	2.2	3.1	0.2	1.8	0.3
Paraguay	1.3	3.6	34.9	3.4	11.1	68.4	1.5	3.1	49.8
Peru	84.8	84.2	209.4	19.7	12.7	51.8	13.6	8.2	12.6
Suriname	1.2	0.6	5.1	0.2	0.2	0.0	0.2	0.2	0.5
Uruguay	21.1	27.6	54.2	56.2	41.2	70.6	3.6	3.0	4.0
Venezuela (Bolivarian Republic of)	113.0	205.0	190.0	77.5	119.0	50.0	50.5	110.0	60.0

Source: FAOSTAT.

TABLE 4

Nutrient balance in Brazil, 2002 (*kg/ha*)

Region	N	P_2O_5	K_2O
North	-21.4	-7.4	-10.9
Northeast	-11.8	-3.8	-3.9
Centre-west	-8.6	-8.5	-4.7
Southeast	-20.4	-4.8	-1.4
South	-20.9	-17.4	-10.9
Average	**-16.6**	**-8.3**	**-6.3**

phosphorus, potassium and magnesium are inadequately supplied (PPIC, 2004). The crop uptake of K is quite high but much remains in the straw. Improved varieties respond to K, especially when given adequate N and P. Response to K is generally greater on sandy soils.

Two sites at Pitipo and Vista Florida, in the rice production area of Chiclayo, were selected for testing different combinations of nutrients (PPIC, 2004):

- K_2O: 0, 37, 74 and 111 kg/ha
- MgO: 0, 15 and 30 kg/ha
- N: 260 kg/ha (with all treatments)
- P_2O_5: 46 kg/ha (with all treatments)

In 2003, in terms of grain quality, the proportion of whole grain in the sample equalled 49 percent for the control treatment (0 K, 0 Mg) and 63 percent for the treatment supplying 37 kg K_2O/ha plus 15 kg MgO/ha.

In 2004, there was a significant response to increasing K rates across Mg rates as follows:

- 0 kg K_2O = 9 592 kg/ha
- 37 kg K_2O = 9 716 kg/ha
- 74 kg K_2O = 10 023 kg/ha
- 111 kg K_2O = 10 217 kg/ha

The interaction between K and Mg was evident in the percentage of undeveloped grain in the sample. The treatment supplying 0 kg K_2O and 0 kg MgO had 12 percent undeveloped grain and the treatment supplying 111 kg K_2O and 30 kg MgO had 8 percent undeveloped grain.

As an example of fertilizer use in this region, in terms of kg/ha of N, P_2O_5, K_2O and S, the rate is 138-30-0-18 in the north coast (Comunidad San Juan Bautista de Catacaos, Piura) and 267-46-0-36 in Vista Florida-IDAL.

INTEGRATED PLANT NUTRITION MANAGEMENT (IPNM)

A fertile soil provides a sound basis for flexible food production systems that, within the constraints of soil and climate, can grow a wide range of crops to meet changing needs. Integrated plant nutrition management is an indispensable tool for supporting high crop production systems through soil fertility improvement while giving due consideration to ecological concerns.

The basic principle underlying the concept of IPNM is the maintenance and improvement of soil fertility through integration and optimization of all possible plant nutrient resources (i.e. organic, inorganic and biological) appropriate to individual farming situations in their ecological, social and economic perspective, for increased crop productivity and quality. For developing IPNM practices, the cropping systems rather than an individual crop, and the farming systems rather than the individual field, are the focus of attention. The objectives of IPNM are to:

- maintain or enhance soil productivity through balanced use of mineral fertilizers combined with organic and biological sources of plant nutrients;
- improve the stock of plant nutrients in the soil; and
- improve the efficiency of plant nutrients, thus limiting losses to the environment.

IPNM offers great potential, therefore, in terms of:
- saving of resources;
- environment protection; and
- economic cropping.

Components

Soil, mineral fertilizers, organic matter and atmospheric nitrogen, fixed by microorganisms or carried down in precipitation, are the major sources of plant nutrients. The natural plant nutrients found in the soil are deposited from the air or water, through nitrogen fixation and the weathering of soil mineral particles. Vegetation consumes a proportion of these nutrients; some are geographically redistributed by runoff; and some are lost by volatilization, fixation and leaching. Farmers harvest the natural supply of these nutrients for their crops and reorganize their distribution in space and time through their production systems.

Soil resources

Soils contain natural reserves of plant nutrients in quantities that depend on soil composition and the stage of weathering. These reserves are often in forms which are unavailable to plants and only a small portion is released each year through biological activity or chemical processes. This release is much too slow to compensate for the removal of nutrients from agricultural production, especially in the humid tropics where soils are strongly weathered. The quantities (or stock) of plant nutrients available for a crop are determined by:
- the supply of nutrients to the crop from internal and external sources;
- the uptake of nutrients by the crop; and
- losses of plant nutrient to the environment.

To enhance the soil nutrient supply, it is necessary to reduce nutrient loss by suitable soil management practices: improving problem soils to mobilize availability of nutrients and adopting appropriate crop varieties, cultural practices and cropping systems to maximize the utilization of available nutrients.

Organic resources

Organic manures are valuable by-products of farming and allied industries, derived from plant and animal sources. Available organic resources include farmyard manure and animal droppings, crop waste and residue, sewage sludge and other human waste, as well as various forms of industrial waste. Improvements in the use of organic nutrient sources can be sought through enhanced and improved organic recycling and better product quality. Organic nutrient resources are not only an effective means of supplementing nutrient availability, but they also improve the bio-physico properties of the soil, enhance fertilizer-use efficiency and are beneficial to the environment.

The following composting method is promoted in Ecuador within the framework of the FAO Special Programme for Food Security (TCP/ECU/8922).

- **Materials:**
  - animal manure: from cows, pigs, poultry, horses, donkeys, ducks etc.
  - crop residues and weeds: maize, bean, faba bean, groundnut, coffee and weeds
  - others: industrial waste, ash and phosphate rock
  - wood cuttings
  - top soil from the forest or from an uncultivated or sparingly cultivated area
  - fresh water

- **Layers:**
  - 1 layer of crop residues (20 cm)
  - 1 layer of top soil (2 cm)
  - 1 layer of manure (5-10 cm)
  - ash or phosphate rock (50 g spread per m^2)
  - fresh water (sprinkled)

  Repeat the above steps until a height of about 1-1.2 m is reached. It is recommended to first construct a lattice of old branches, positioning two or three wood cuttings vertically in order to facilitate ventilation. An appropriate size for the heap is 2 × 1-1.2 × 1-1.2 m.

- **Water:** Once a week, water must be added to the heap, but not in excess in order to avoid the leaching of nutrients.
- **Air:** After 3 weeks, the heap must be mixed to ensure that all materials reach the centre.

- **Temperature:** During the process, the temperature rises to 60°-70°C and most weed seeds and pathogens are killed. The ideal temperature is 60°C.
- **Duration:** 2-3 months.

Biological resources

Legumes contribute to soil fertility directly through their unique ability – in association with Rhizobia – to fix atmospheric nitrogen. There are good prospects for enhancing exploitation of biological resources, i.e. Rhizobium-legume symbiosis and other associations such as Blue-green algae, Azolla, Actinomycetes, Azotobacter and Azospirillum in rice-based cropping systems. Rhizobium-legume associations are by far the most important sources of fixed N. Average N fixation rates are around 100 kg/N/ha/year, but levels of 200 kg can be obtained by adequate selection of Rhizobium strains.

On non-irrigated cultivated land, grain legumes are essentially considered, such as cowpea, groundnut, bean, chickpea, green gram, lentil and pigeon-pea. N_2-fixing cyanobacteria make a significant contribution to paddy rice growing systems. Sesbania, a leguminous tree grown in rice fields as green manure, can fix up to 500 kg N/ha/year. The most commonly used in rice cultivation is the Azolla-Anabaena association. This association fixes N in the order of 100-200 kg/ha/year.

Mineral fertilizer resources

The role of mineral fertilizers in plant nutrition for sustaining and increasing agricultural production is well recognized. In order to further improve fertilizer-use efficiency, reduce losses to the environment and promote the judicious use of mineral plant nutrient sources, the integrated plant nutrition systems (IPNS) approach aims to:

- provide recommendations for a cropping system rather than a single crop in the system;
- improve all the production factors and eliminate limiting factors, including secondary and micro-nutrients; and
- minimize nutrient losses in the field through appropriate timing and methods of application.

Operational approach

A simplified operational approach is as follows:

- Carry out a benchmark survey to assess actual availability of farm residues and other organic sources which are not appropriately used at present and could be used effectively for agricultural production.
- Select major multiple cropping systems (including one grain or forage legume) – depending on agro-ecological conditions, produce markets, dietary preferences etc.
- Follow appropriate soil management and conservation practices, including improvement of problem soils and crop management practices.
- Schedule nutrient application rates, including secondary and micronutrients for the cropping system as a whole.
- Apply N, P, K and micronutrients to the crop which makes best use of the nutrient in question; the following crop benefits from the residual effect.
- Use all available organic materials for the farm lands; establish programmes for quick-growing trees for fuel wood on common lands and along the borders of farms, thereby reducing dependence on cattle dung for fuel; install biogas plants where appropriate.
- Adopt suitable technologies for good quality compost production from easily available farm or agricultural wastes and other organic sources; apply compost and farmyard manure (FYM) in the most appropriate season.
- Where appropriate, practise alley-cropping or green manuring or introduce a legume crop (grain or fodder) in the cropping system, inoculating, if necessary, with efficient Rhizobium strains.
- Introduce effective strains of Azolla and blue-green algae in rice-based cropping systems in appropriate agro-ecological situations.
- Assess nutrients supplied through organic sources and apply the balance of the recommended dose through mineral fertilizers, taking into account a 15 percent increase in efficiency of the mineral fertilizers due to the complementary effects of the organic sources and mineral fertilizers.
- Monitor soil nutrient status against crop yield performance and make any necessary adjustments to the fertilizer schedule.
- Perform an economic evaluation of the integrated system.

The precise model for each country depends on the agro-ecological conditions, cropping systems and available plant nutrient resources, as well as the infrastructural, organizational, research and development support available.

Long-term experimental results

The sustainability of the rice cropping system is important for food security. Intensive cropping with no return of crop residues and other organic inputs results in loss of soil organic matter (SOM) and nutrient supply and is assumed to be non-sustainable. Seven treatments comprising various combinations of green manure (GM; *Sesbania cannabina* L.), wheat straw (WS), FYM and urea were applied to study the effects on yield and yield trend, P and K balance, and soil fertility, as part of a rice-wheat experiment (1988-2000) on loamy sand in Punjab, India (Table 5).

Rice yields were comparable with GM + urea, WS + GM + urea, and urea alone, but yields were reduced when FYM was supplemented with N. With the exception of one year, the integrated use of FYM and GM produced rice yields which were equal to or higher than with other GM-based treatments. WS incorporation reduced average rice yields by 7 percent compared with WS removal. After 5 years of continuous application, FYM and WS were on a par in terms of increasing rice yields. Organic materials applied to rice had no residual effect on wheat yield, with the exception of FYM, which increased yield by about 6 percent compared with urea alone. Rice yield declined by 0.02 to 0.13 tonnes/ha per year, but wheat yields remained unchanged. Soil carbon increased with the application of WS and FYM. Potassium balance was highly negative. Although the causes of yield decline are unknown, inadequate K application and changes in the climatic parameters are possible reasons.

Apparent nutrient balance

The apparent P balance at system level was negative in all treatments except for those containing FYM. The P balance in T1 (control, 0N) was near zero because of less P removal by rice. The negative P balance in T2 (urea-N, 150 kg N/ha) averaged 10.4 kg P/ha/year), suggesting that the current fertilizer P recommendations are not adequate for maintaining long-term soil-supplying capacity.

The apparent K balance was negative in all treatments. The average K balance ranged from -78 kg in the control (T1) to -151 kg K/ha/year in urea N (T2). When WS or FYM was recycled (T4-T7), the K balance was still negative, although less so. Despite substantial inputs from irrigation water, the K balance was negative. The total K uptake by the rice-wheat system averaged 285 kg K/ha/year in T2, which is maintained at a relatively high rate of K uptake, despite the application of insufficient

TABLE 5
Long-term effects of organic and inorganic fertilizers on grain yield of rice and wheat

Year	Treatment number [a]						
	T1	T2	T3	T4	T5	T6	T7
	Rice grain yield (*tonnes/ha*) [b]						
1988	3.97 e	6.29 bc	6.56 b	6.24 cd	6.94 a	5.81 d	7.05 a
1989	4.64 b	6.57 a	6.48 a	6.40 a	6.56 a	6.30 a	6.70 a
1990	3.67 d	6.19 a	6.15 a	5.65 b	6.35 a	4.60 c	6.10 a
1991	4.23 d	6.49 b	6.47 b	6.28 b	6.66 ab	5.72 c	6.90 a
1992	4.10 d	5.70 b	5.80 b	5.20 c	5.60 b	6.04 c	6.50 a
1993	3.44 d	5.59 b	5.54 b	4.82 c	5.50 b	4.80 c	6.10 a
1994	2.79 b	4.08 a	3.92 a	3.93 a	3.92 a	3.93 a	4.04 a
1995	2.64 d	5.20 ab	5.50 a	4.60 c	5.34 a	4.63 c	4.94 b
1996	3.90 d	5.52 a	5.30 ab	5.00 bc	5.23 abc	4.83 c	5.64 a
1997	4.36 b	6.64 a	6.25 a	6.32 a	6.57 a	6.38 c	6.59 a
1998	3.97 d	5.02 bc	5.05 abc	5.06 abc	5.24 ab	4.90 c	5.35 a
1999	4.02 c	5.54 b	5.42 b	5.16 b	5.26 b	5.17 b	5.98 a
	Mean wheat grain yield (*tonnes/ha*) [b]						
1988-2000	4.37 bc	4.41 bc	4.41 bc	4.32 c	4.44 b	4.65 a	4.71 a

[a] T1 - control, 0N; T2 - urea-N, 150 kg N/ha; T3 - GM + urea-N (total N additions in T3, T5 and T6 were adjusted to 150 kg N/ha with urea); T4 - WS + urea-N; T5 - WS + GM + urea-N; T6 - FYM + urea-N; T7 - FYM + GM (no inorganic N was applied to T7).
[b] Values within each row followed by the same letter do not differ significantly ($P < 0.05$) by Duncan's multiple range test.
Source: Singh *et al.*, 2004.

amounts of K. However, the large negative K balance suggests that the system will not be able to sustain the K supply in the long term. The major fraction of K uptake, however, remains in rice straw; thus, recycling of straw will dramatically change the K balance, keeping it within reasonable limits.

Example of a project in Bolivia

Project GCPF/BOL/018/NET, "Soil management and plant nutrition in farming systems – Fertisuelos", became operational in July 1987. The main activities were:

- Promotion of the correct use of mineral fertilizers based on soil analysis and trials and demonstrations conducted in farmers' fields with potatoes, maize, rice and wheat.
- Development of a capitalization process at farm level based on the use of agricultural inputs made available on a seasonal credit basis.
- Training of farmers and extension agents.

In addition to these activities, the project focused on the identification of the limiting factors responsible for the low yields of food crops in the three cropping zones of the country, i.e. the highands, the valleys and the lowlands. Since then, a new set of technical innovations has been tested through a network of demonstration farms emphasizing:

- more rational management of manure and other recyclable organic residues;
- higher fodder production from pastures and use of fallow land, and corresponding improvement of soil fertility; and
- improvement of cultivation practices, e.g. land preparation to increase soil water reserves, plant density, weed control and erosion control.

The project established that significant increases in crop yields can be obtained through the application of the recommended technical packages. Potato yields improved from 12 tonnes/ha (mineral fertilizer plots) to 22.8 tonnes/ha (IPNS plots). Similarly, maize yields improved from 3.6 to 4.9 tonnes/ha and rice from 3.0 to 5.6 tonnes/ha. The advances made in the management of manure and the results of organomineral fertilization revealed the possibilities of recycling local sources of organic matter in a more efficient manner.

In rice, the effects of organomineral fertilizer and plant density were tested. The treatments are shown in Table 6.

TABLE 6
Treatments

	$N\text{-}P_2O_5$	+	Manure (*tonnes/ha*)	Plant density (*pl/m*^{2})
	15-15	+	5	260
	30-30	+	5	260
	60-60	+	5	260
Control:	**Farmer's plot without fertilizer**			**130**

With 30-30 + 5 tonnes/ha manure, farmers' plot yield was 2-3 tonnes/ha, while yield in the plots with adequate density of 260 pl/m^2 was 5-6 tonnes/ha.

The project successfully demonstrated that, with correct utilization of organic resources, it is possible to:

- conserve the soil fertility;
- make agricultural production more sustainable; and
- minimize the costs and economic risks associated with high dosage of fertilizers.

Extending IPNM for wider adoption

Farmers should be motivated to make optimum use of organic, inorganic and biological fertilizers. They need to be made aware of their nutrient-supplying potential and the resulting physico-chemical and biological benefits for the soil, with enhanced productivity.

Departments of agricultural extension, private enterprises and NGOs (non-governmental organizations), together with research and educational institutes, have a vital role to play in the promotion of IPNM practices to farmers. Efforts should focus on creating awareness and expertise in farmers in the efficient use of those fertilizers, locally-available organic manures and biofertilizers which are most suitable to the needs of the area and the cropping systems as a whole.

In order to promote adoption of the technology, a programme could be set up to establish knowledgeable groups of farmers who have been trained in appropriate IPNM techniques, and who have the necessary potential to transmit expertise to fellow farmers. One possible means of achieving this is the organization of farmer field schools (FFS).

For the effective implementation of improved agricultural practices, adopting a holistic approach, extension workers must be effective and innovative managers. Farmers require exposure to improved technology and practical training; they must be adaptable and capable of organization with the collaborative efforts of research and extension services.

Coordination of the efforts of all agencies and institutions would lead to speedy and effective implementation of the programme. National governments have the role of central coordinating agency.

CONCLUSION

There are good possibilities for closing the yield gap in irrigated rice in Latin America and the Caribbean. Suboptimal nutrient supply has been identified as one of the major reasons for the yield gap. Integrated plant nutrition for rice-based cropping systems ensuring optimum and efficient use of organic, mineral and bionutrient resources could, therefore, be an effective instrument for closing the rice yield gap. It is also important that nutrient balances in rice-based cropping systems are established.

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Incidence de la gestion intégrée des fertilisants sur la production durable de riz, en particulier dans les pays d'Amérique latine

Le riz irrigué et les systèmes privilégiés de culture pluviale représentent approximativement 70 pour cent de la production totale de riz en Amérique latine et dans les Caraïbes. L'adoption de génotypes à rendement élevé est importante dans la région. Cela dit, les rendements obtenus dans les exploitations restent bien inférieurs au potentiel de rendement. L'écart de rendement est évident dans les systèmes de production du riz irrigué. Si l'on réduit cet écart il sera possible de renforcer de manière très nette la sécurité alimentaire dans les pays d'Amérique latine et des Caraïbes.

La mauvaise fertilisation des cultures explique en grande partie les écarts de rendement. Une amélioration de la gestion des fertilisants aura donc des répercussions importantes sur la production durable de riz qui requiert une gestion intégrée de toutes les ressources disponibles en nutriments: sols, matières organiques, minéraux et engrais biologiques. La gestion intégrée des nutriments assure le maintien et parfois même l'amélioration de la fertilité du sol par une utilisation équilibrée et adaptée des engrais minéraux associée à des apports organiques et biologiques, qui se traduit par une meilleure efficience des éléments nutritifs, une productivité accrue des cultures et une réduction des pertes en éléments nutritifs affectant l'environnement.

Les systèmes de culture reposant sur le riz permettent de tirer parti de manière idéale de la gestion intégrée des nutriments. La fixation biologique de l'azote (FBA) par une algue vert-bleu dans les eaux de décrue et par une bactérie hétérotrophique dans les zones radicalaires du riz peuvent contribuer de manière significative à l'équilibre en azote Les apports organiques en azote, comme le fumier et l'engrais vert peuvent être utilisés de manière efficace en association avec des engrais minéraux. Il est également possible d'accroître les quantités d'azote par le biais de l'azolla, malgré certaines contraintes, comme l'augmentation des coûts de main-d'œuvre.

La gestion intégrée des nutriments a permis d'obtenir, dans certaines parties du monde, des résultats encourageants pour la production rizicole. Les expériences menées dans certains pays en vue de soutenir la production rizicole par le recours à la gestion intégrée des nutriments sont présentées dans le présent article.

Repercusiones de la gestión integrada de nutrientes en la producción sostenible del arroz con referencia especial a los países de América Latina

La producción en régimen de regadío y los sistemas de tierras altas más favorecidos representan en la actualidad cerca del 70 % del total de la producción de arroz en América Latina y el Caribe. Los genotipos de alto rendimiento tienen una cobertura importante en la región, pero los rendimientos de los agricultores siguen estando muy por debajo del potencial de rendimiento de los cultivos. La brecha de rendimientos resulta evidente en los sistemas de producción de arroz en régimen de regadío, por lo que salvar esta brecha se presenta como la oportunidad más prometedora de reforzar la seguridad alimentaria en América Latina y el Caribe.

La nutrición inadecuada de los cultivos constituye uno de los motivos principales de la brecha de rendimientos. Mejorar la gestión de los nutrientes de cultivos tendrá una repercusión importante en la producción sostenible del arroz, para la cual se requiere la gestión integrada de todos los recursos de nutrientes disponibles, es decir, el suelo, los productos orgánicos, los minerales y los biofertilizantes. La gestión integrada de nutrientes garantiza el mantenimiento y la posible mejora de la fertilidad del suelo gracias a la utilización equilibrada y prudente de fertilizantes minerales combinados con fuentes orgánicas y biológicas, lo cual se traduce en una mejora de la eficacia de los nutrientes, el incremento de la productividad de los cultivos y la reducción al mínimo de las pérdidas de nutrientes al medio ambiente.

Los sistemas de cultivos basados en el arroz ofrecen una oportunidad ideal para extraer beneficios de la gestión integrada de nutrientes. La fijación biológica del nitrógeno natural a través de algas verde-azuladas en aguas de inundación y mediante bacterias heterótrofas en la zona de raíz del arroz puede suponer una importante aportación al balance del nitrógeno. Las fuentes orgánicas de nitrógeno, como el estiércol de granja y el abono verde de legumbre, pueden utilizarse de forma eficaz como insumos de nitrógeno junto con el nitrógeno de los fertilizantes minerales. También cabe la posibilidad de complementar las necesidades de nitrógeno mediante la azolla, pese a presentar algunas limitaciones, como los costos adicionales de mano de obra.

Las prácticas de gestión integrada de nutrientes en determinadas partes del mundo han revelado resultados alentadores en relación con la producción del arroz. Aquí se muestran las experiencias de algunos países en el sostenimiento de la producción del arroz a través de la aplicación de prácticas de gestión integrada de nutrientes.

Using wholegrain rice to promote small and medium enterprises (SMEs)

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Rice is the staple food with the highest level of consumption in the world and the third highest production after wheat and maize. Ninety percent of global rice production occurs in tropical and subtropical Asian countries. In several countries of Africa, Latin America and the Caribbean, rice is a major staple and is produced in considerable quantities. It is estimated that by 2025, 10 billion people will depend on rice as a principal food and demand will reach 880 million tonnes. The rice sector is an important part of the economy in many Asian countries, providing employment and contributing to the gross domestic product (GDP).

Nevertheless, the evolution of the price of paddy rice in recent years has not been particularly advantageous for small farmers. Higher paddy prices have motivated rice-producing developing countries to create opportunities for adding value to traditional milled rice and its by-products. The Agricultural and Food Engineering Technologies Service (AGST) of FAO has a mandate to support such activities; in addition to technical support and organization, funding support is required to improve the development of small rice enterprises.

The International Rice Commission (IRC) comprises 61 member countries. Its international conference, organized every 4 years, is an important event for members to share recent experiences related to rice production and post-production.

Asian rice farmers traditionally use wholegrain rice and its by-products at artisan level. This experience could be shared with other countries and used as a basis to promote development of the agro-industry sector. Some governments and research institutions have carried out activities and developed strategies to promote small industry through the integral and efficient use of paddy rice. In recent years, AGST-FAO has prepared technical reports on this subject, identifying ways to strengthen the small rice industry sector:

The use of high-yielding varieties (HYVs) presents new challenges in terms of infrastructure development, and also in terms of innovative technologies for adding value to rice and its by-products (a good source of employment and income generation).

The establishment of viable agroprocessing enterprises in rural areas producing rice is crucial, not only in Asia but in other developing countries of Africa and Latin America; investment in technologies that are affordable and add quality and commercial value to rice products and by-products will enhance the demand for farm produce.

The revision of whole grain rice utilization is important for promoting the small rice industry (rice by-products are currently under-used, resulting in problems of handling and pollution).

BACKGROUND

Carbohydrate demand declines as income increases; likewise, if income is low, the demand for rice increases. For some Asian countries, the decline in rice consumption is a matter for concern, since it is the traditional staple food and a major source of energy, protein, thiamine (B1), riboflavin (B2), niacin, iron and calcium (Hadiwigeno, 1997). The negative trend of rice consumption is partly due to an improvement in living standards. There is, therefore, a risk that rice may develop a negative image and be perceived as food for the poor. The changes in food consumption patterns depend on three major factors:

- taste and preference (especially for protein foods);
- income; and
- price of rice in relation to price of substitutes.

In the face of a decline in boiled rice consumption as living standards improve, some food research institutions have been modernizing the processes related to rice food, to promote consumption of new, improved rice products and convenience rice foods (Hadiwigeno, 1997).

The total production of paddy or rough rice was around 615 million tonnes in 2005. About 365 million tonnes of milled rice are produced in developing countries and

18 million tonnes in developed countries (Table 1). In addition to the milled rice derived from the main processed product, there is also a large volume of by-products, including the husk, bran and broken grains. Therefore, small rice farmers could benefit from useful technologies for rice products and by-products. Efficient technologies can enhance quality and safety in milling rice processing and offer great potential in terms of the utilization of by-products. In both cases, there is added value which increases returns. Strengthening the rice small industry sector is in line with the Millennium Development Goals (MDG) which aim to reduce extreme poverty and eradicate hunger in poor countries.

It is important to apply modern or innovative processing technologies to traditional rice products. This applies in particular to those countries which have entered the General Agreement on Tariffs and Trade (GATT) and must upgrade the uniformity, quality and shelf-life of the product and comply with various requirements (e.g. specification of ingredients). Therefore, the improvement of rice-processing small and medium enterprises (SMEs) – whether for rice products or by-products – is a matter of great importance within FAO's Technical Cooperation Programme, and specifically within AGST.

The main approach is to enhance capacity-building for rice in developing countries by facilitating the interchange and transfer of technologies to add value and create opportunities for income generation and employment among farmers or people associated with these activities within the food chain of rice and rice by-products. The appropriate technical use of paddy rice should be seen as an important action to be carried out by rice farmers and agroprocessors to convert it into an efficient and profitable business through implementation of cost-effective and environmentally friendly methods and technologies. In some countries (e.g. Indonesia), small-scale rice industry development has had a significant impact on the GDP, resulting in the reduction of poverty to some extent. Thus, the promotion of the small-scale food industry is a helpful alternative to be exploited in developing countries in order to improve the rice agricultural sector socio-economically. Although the small-scale food industry – like any other small enterprise – cannot increase the per caput income very rapidly, it can open up more job opportunities than medium or large-scale industries; this is clearly demonstrated in Indonesia, where rice milling is the most important small-scale food processing industry (Damardjati, 1995).

Many rice-producing countries are poor and need to develop national strategies to enhance the capacity for improving the efficiency of technologies used to add value to rice and its by-products. In this regard, small and medium rice agro-industry development represents a valuable alternative, not only for the small and medium rice producer but for others interested in using rice in a more integral and efficient manner.

WHOLEGRAIN RICE STRUCTURE, PROPERTIES AND COMPOSITION

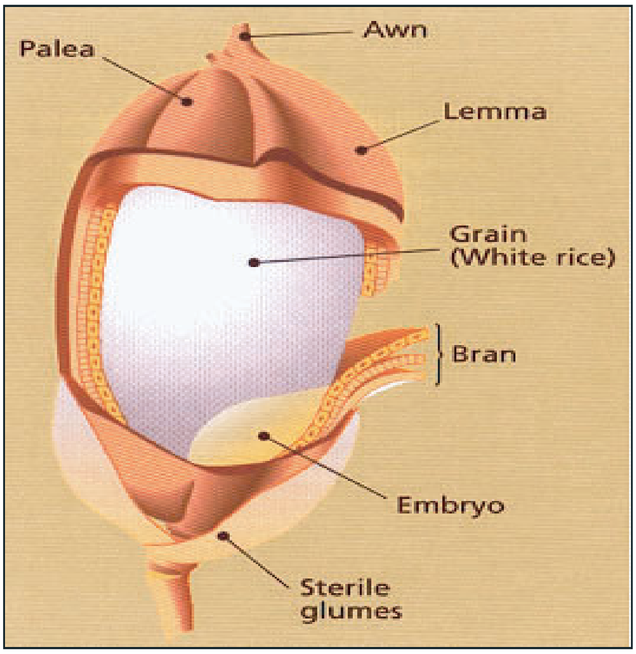
Freshly harvested rice is called paddy grain or rough rice. The pearly white grain used for cooking is the centre of the rice seed and it is covered and protected by the husk

TABLE 1
Paddy rice world production and milled rice, utilization, export and import

Region	Rough rice production 2005 (*tonnes*)	Milled paddy rice (*tonnes*)		
		Rice milled equivalent-domestic supply (2003)	Export (2004)	Import (2004)
Developing countries	589 390 422	364 783 250	21 689 813	16 602 715
Latin America and Caribbean	26 370 717	16 753 623	533 866	1 242 881
Africa	18 565 960	19 326 043	828 569	5 807 222
Near East	10 830 748	10 558 944	964 002	4 810 867
Far East	539 820 645	322 461 872	20 176 024	5 460 446
Developed countries	25 264 473	17 756 051	2 596 464	3 169 513
United States of America	10 012 190	3 976 280	1 675 042	447 728
Europe	3 235 900	3 872 178	1 454 778	838 960
Japan	10 989 000	7 969 912	-	-
Total for Asia	556 018 828	337 799 621	20 385 158	10 225 470
World	**614 654 895**	**382 539 301**	**24 286 277**	**19 772 228**

Source: Yap, 1995 (adapted); FAOSTAT, 2006.

FIGURE 1
Rice grain section showing protective layers



Source: RIRDC, 2003.

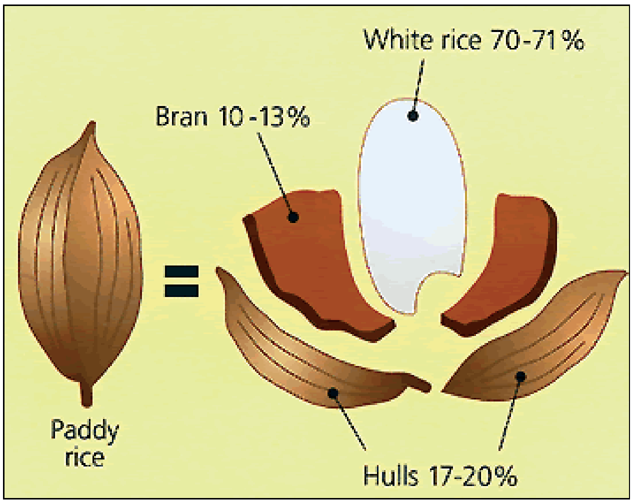
or hull which is composed of the palea, lemma and sterile glumes. Inside the husk, the familiar white grain is covered by a layer called bran. The embryo, a small structure at the base of the grain, is also contained within the bran layer. Together, the grain, embryo and bran are called brown rice (Figure 1).

Rough or paddy rice consists of an outer protective layer covering the husk (17-20 percent), the bran (10-13 percent) and the white rice (70-71 percent). Paddy rice is the whole grain as taken off the plant at harvesting; the white rice grain which is eaten accounts for less than three-quarters of the weight of a paddy rice grain which also includes the hull and bran (Figure 2). The palea, lemma and sterile glumes are removed from paddy rice in the first stage of the milling process, called de-hulling. Machines rub off the bran and embryo to leave polished rice or white rice. A polished rice grain contains approximately 94 percent starch and 5 percent protein.

Rice is the staple food in at least 17 countries in Asia and the Pacific, nine countries in North, Central and South America and the Caribbean, one country in North Africa and seven countries in sub-Saharan Africa (FAO, 2004). In developing countries, rice accounts for 715 kcal/caput/day, providing 27 percent of the dietary energy supply, 20 percent of dietary protein and 3 percent of dietary fat. The brown rice is the edible part of the rice grain. Levels of dietary fibre, minerals and B vitamins are highest in the bran and lowest in the aleurone layers. Rice is a good source of B vitamins (thiamine, riboflavin and niacin), but contains little or no vitamins C, D or beta-carotene (precursor of vitamin A) (Kennedy, Burlingame and Nguyen, 2002). The amino acid profile of rice is high in glutamic and aspartic acids, but low in lysine (Juliano, 1997). The anti-nutritional factors, most of which are concentrated in the bran, are phytate, trypsin inhibitor, oryzacystatin and haemagglutinin-lectin. The availability of iron and zinc in typical Asian rice diets is generally low: they come mainly from plant sources, and rice and legumes contain phytate which binds minerals and proteins including enzymes (Calloway, 1995). Table 2 shows the composition of rice and its edible fraction.

In recent years, in some countries (e.g. Japan), rice bran has been associated with good health, thanks to several active components, including: rice bran oil (reduces cholesterol), γ-Oryzanol and Ferulic acid (antioxidants), Inositol (for liver function and healthy hair) and sterols (for cholesterol metabolism). These components offer potential in both the food and the cosmetic industry (Tsuno-Co., 2004). Moreover, the hypocholesterolaemic effects of stabilized rice bran reduce plasma cholesterol due to the presence of a unsaponificable fraction and the effect of rice bran hemi cellulose (Suzuki *et al.*, 1962).

FIGURE 2
Paddy rice components



Source: RIRDC, 2003.

TABLE 2
Composition per 100 g of rough rice and its edible fraction

Nutrient (in 100 g)	Rough rice	Brown rice	Milled rice	Rice bran	Rice hull
Moisture	14	14	14	14	14
Protein (*g*)	5.5-7.7	7.1-8.3	6.3-7.1	11.3-14.9	2.0-2.8
Fat (*g*)	1.5-2.3	1.6-2.8	0.3-0.5	15-29.7	0.3-0.8
Ash (*g*)	2.9-5.2	1.0-1.5	0.3-0.8	6.6-9.9	13.2-21
Crude fibre (*g*)	7.2-10.4	0.6-1.0	0.2-0.5	7-11.4	34.5-45.9
Dietary fibre (*g*)	16.4-19.2	2.9-3.9	0.7-2.3	24-29	66-74
CHOS (*g*)	64-73	73-87	77-89	34-62	22-34
(*Kcal*)	378	363-385	349-373	394-476	265-332
Lysine (*g/16g N*)	3.1-4.7	3.7-4.1	3.2-4.0	4.8-5.4	3.8-5.4
Thiamine (*mg*)	0.26-0.33	0.29-0.61	0.02-0.11	1.20-2.40	0.09-0.21
Riboflavin (*mg*)	0.06-0.11	0.04-0.14	0.02-0.06	0.18-0.43	0.05-0.07
Niacin (*mg*)	2.9-5.6	3.5-5.3	1.3-2.4	26.7-49.9	1.6-4.2
Calcium (*mg*)	10-80	10-50	10-30	30-120	60-130
Phosphorus (*mg*)	0.17-0.39	0.17-0.43	0.08-0.15	1.1-2.5	0.03-0.07
Iron (*mg*)	1.4 - 6.0	0.2-5.2	0.2-2.8	8.6-43	3.9-9.5
Zinc (*mg*)	1.7-3.1	0.6-2.8	0.6-2.3	4.3-25.8	0.9--4.0
Density (g/cm^3)	1.17-1.23	1.31	1.44-1.46	1.16-1.29	0.67-0.74
Bulk density (g/cm^3)	0.56-0.64	0.68	0.78-0.85	0.20-0.40	0.10-0.16

Source: Juliano, 1985.

POST-HARVESTING OF RICE ASSOCIATED WITH QUALITY

During post-harvest operations related to rice, an efficient on-farm handling, storage, processing and distribution system is essential to ensure acceptable quality and safety of the grain. Environmental conditions during grain ripening and drying in the field may affect the processing characteristics of the rice grain (Juliano, 1996). Early-maturing (90-100 days) tends to be more immature than medium-maturing rice (130-140 days). Immature grains reduce head rice yield and result in completely chalky grains. Thinner grains also tend to have lower amounts of brown rice and total and head-milled rice than normal grains (Wadsworth and Hayes, 1991). Drying is the most critical post-harvest operation, particularly in the wet season, for maintaining the quality of the rice grain (Juliano, 1996). Aflatoxin is produced mainly in the bran polish fraction of brown rice (Ilag and Juliano, 1982).

During post-harvest operations, numerous factors can affect quality:

- Stack-burning (yellowing) occurs when wet grain, particularly unthreshed grain, is piled without any provision for ventilation. Microbial respiration of the thermophilic fungi may heat the rice to over 60°C (Phillips *et al*., 1988). The resulting milled rice becomes hard, translucent and yellow, regardless of variety, due to the effects of heating rather than direct microbial infestation. Yellowing reduces the lysine content of rice by about 10 percent, resulting in a drop in net protein utilization (Eggum *et al*., 1984).
- Rice hull tightness provides better protection for the brown rice from infestation by insects and microorganisms. Parboiled rice usually has a loose hull as a result of starch gelatinization and swelling (Juliano, 1997).
- Grain breakage during milling is caused by the preformed fissures in brown rice which result from moisture absorption stress during storage and milling (Kunze, 1985). The critical moisture content is that below which grain fissure is 15-16 percent for susceptible rice and 12-14 percent for resistant varieties (Juliano and Perez, 1993). Immature grains become small, thin and chalky broken. Chalky portions of rice with high amylose content in the endosperm are subject to grain breakage because of the presence of air space and the loose arrangement of the cell contents.
- Ageing occurs during the first 3-4 months after harvest in rough, brown or milled rice at temperatures above 15°C, when the endosperm:
  - becomes harder, resulting in higher total and head-milled rice yields and more volume expansion and water absorption during cooking (with fewer solids in cooking gruel);
  - becomes slightly yellow; and
  - loses its aroma.

- Shelf life – due to damaged aleurone cells, milled rice and brown rice also experience fat rancidity as a result of lipase action on fat to produce free fatty acids and the oxidation of the released unsaturated fatty acids by the action of lipoxygenase. The major carbonyl compound produced is hexanal, detectable by Japanese consumers 1 month after milling. Fresh, well-milled rice is, therefore, the preferred raw material for processed rice products because there is a lower content of surface fat subject to rancidity. Shelf-life is longest for rough rice, followed by brown rice; it is shortest for milled rice. Thermally-processed rice products are more stable and tend not to suffer from this type of oxidation.

De-hulling and milling of paddy rice

One of the main processing methods applied to paddy rice is milling, and the efficiency of milling is calculated as a percentage of the whole grain obtained after milling. The main operations involved in paddy rice milling are:

- cleaning;
- de-husking or de-hulling to obtain brown rice;
- whitening of brown rice to obtain white rice; and
- polishing of white rice to finally obtain polished white rice.

An efficient rice mill will produce more than 50 percent head rice, 5-15 percent large brokens and 5-15 percent small broken kernels. In the Engelberg or huller-type mills, de-hulling and milling are done in a single step, resulting in increased grain breakage and by-products which are a mixture of hull and bran (IRRI, 2006).

The weight of the whole white grains left after milling is calculated as a percentage of the total weight of the paddy rice. Breakage of grain occurs during milling for various reasons, including the presence of chalky or opaque grains which are generally softer than translucent grains and consequently prone to breakage during milling. Parboiling increases the percentage of head rice because it gelatinizes the starch in the grain, which results in firmer grains after drying.

Two types of rice mill are generally used in developing countries:

- Village mill, with three main outputs:
  - milled rice (mixture of whole grains and large and small brokens);
  - husk; and
  - bran.
- Commercial mill, with a multi-pass system producing six outputs:
  - head rice (the main product of grading);
  - broken grains (a co-product of grading);
  - brewer's rice (a by-product of sifter);
  - coarse bran (a by-product of first whitener);
  - fine bran/meal (a by-product of second whitener/polisher); and
  - husk or hull (a by-product of husking).

Head rice is milled rice with a length greater or equal to three-quarters of the average length of the whole kernel. Head rice recovery varies from 25 to 65 percent in the standard rice milling industry (IRRI, 2006).

Two major advances in rice milling are the humidifying rice-milling machine and the rice moisture conditioner for high-moisture milling (Satake, 1990). The brown rice is humidified through pressurized water mist via a hollow shaft. An additional 0.3 to 0.4 percent moisture then softens the surface, resulting in: more efficient bran removal (i.e. higher total and head-milled rice yields); a 2°C lower temperature rise; and minimum moisture loss. More glossy milled rice is obtained and gelatinization of surface starch during milling has been observed (Kohlwey, 1992).

The rice milling industry can promote small and medium agrobusinesses through improved quality control of paddy rice and the milling process. Rice quality improvement should be in line with consumer preferences and affordability. Quality is not the only means for promoting rice at national and international level in order to obtain higher prices. Other potential niches for rice milled products exist, for example organic rice and brown rice:

- Organic certification requires special conditions for production, but it opens up market opportunities.
- Brown rice (or husked rice) is minimally processed and retains the bran layers with high nutritional properties; it is recommended to apply parboiling and vacuum and opaque packaging for increased shelf-life.

PROCESSED RICE PRODUCTS

In developed countries, there is a high level of consumption of processed rice products made mainly by large rice-processing enterprises. Developing countries, on the other hand, produce a smaller quantity of processed rice products, and there is therefore a good opportunity to promote the small rice industry. Processed rice products include pre-cooked and quick-cooking rice, noodles, rice cakes and pudding, expanded or puffed rice, baked rice products, fermented rice, rice flour and starch, and are derived from brown rice, milled rice, cooked rice, broken rice, dry-milled flour and rice starch.

Precooked and quick-cooking rice

Precooked rice is used for rice-based convenience food products. These are hermetically sealed in laminated plastic or aluminium-laminated plastic pouches and pasteurized at 120°C under pressure (Juliano and Sakurai, 1985). Before consumption, the aluminium-laminated plastic pouch is warmed directly in hot water for 10 to 15 minutes; plastic pouches may be punctured and heated in a microwave oven for 1 to 2 minutes.

Frozen cooked rice packed in airtight plastic pouches has been in great demand in some countries (e.g. Japan). Likewise, precooked frozen rice is also delivered to chain restaurants, where it is heated in microwave ovens and served. Deep-freezing without dehydration helps prevent cooked rice from retrograding (hardening) (Juliano, 1997).

Other products can be made from precooked rice, for example, dry precooked rice cereal: cereal slurry is prepared, cooked, dried in a double-drum drier, flaked and packaged.

Noodles

Flat and extruded round noodles are traditionally prepared from wet-milled flour that has been ground with a stone or metal mill. The starting material can be whole or broken grains with low fat content. Freshly milled rather than aged rice with a high amylose content is recommended. To make flat rice noodles, a wet-milled rice batter with a consistency of 42 percent rice by weight is placed on a noodle-making machine (Juliano and Sakurai, 1985). In Viet Nam, Thailand and Taiwan, rice paper and egg roll wrapper are prepared from wet-milled high-amylose rice batter.

Rice cakes and pudding

Rice cake is traditionally prepared from waxy milled rice by washing the milled rice, steaming at 100°C for about 15 minutes to 40 percent moisture content, grinding and kneading and then packing in plastic films; it is then pasteurized for 20 minutes at 80°C and left to cool (Juliano and Sakurai, 1985).

Japanese rice pudding consists of waxy rice flour, cornstarch, sugar, water and flavouring mixed and steamed at 100°C and served with sweet bean curd, green tea, coffee, cherries and other fruits (Juliano and Sakurai, 1985). Another type of pudding is prepared by cooking the rice in boiling water, straining and mixing it with milk prior to completion of cooking. Egg yolk, sugar, vanilla and light cream are amalgamated with a variety of fruit combinations. Rice with sweet milk is very popular in Latin America, where it is mixed with cinnamon and scent nail and consumed warm or cold.

Expanded rice products

Puffed and popped rice are traditional breakfast cereals and snack foods. Flaked or beaten brown rice and parboiled milled rice may be converted into puffed rice by heating in hot air or roasting in hot sand. With normal parboiled milled rice, the puffed volume is directly proportional to the intensity of the parboiling (Villarreal and Juliano, 1987).

Continuous explosion-puffing of brown rice was developed in Japan in 1971. The grains are dispersed in a long heating pipe and conveyed by a high-velocity stream of superheated steam (Sagara, 1988). After the rice has been heated and dried in 3 to 10 seconds, it is discharged into the atmosphere through a rotary valve and explosion-puffing takes place. A brown rice expansion ratio of 5.4 is obtained at 6 kg/cm^2 pressure and an outlet steam temperature of 200°C. The puffed product has a starch digestibility of 94 percent after 15 minutes' boiling.

Baked rice products

There has been progress in bread baking in Japan, using a mixture of 10 to 20 percent rice flour and wheat flour, depending on the gluten strength of the wheat flour (Tani, 1985). A mixture of 60 percent rice flour, 30 percent wheat flour and 10 percent vital gluten has also produced good results. Similar dilutions of wheat flour with rice flour and other starchy flours have been developed for bread-making in other countries. It is important that the gelatinization temperature of the starch be low (<70°C) (Bean and Nishita, 1985).

Fermented rice products

Waxy rice wines are prepared by fermenting steamed waxy milled rice with fungi and a yeast starter (Juliano and Sakurai, 1985). A sweet product is produced, which is converted to alcohol as fermentation progresses. The liquid is removed by decantation. Rice wine production in Taiwan uses either *Aspergillum oryzae* or *Rhizopus* sp. for saccharification (Chang, 1988).

Rice vinegar results from the completion of the rice starch fermentation and is a traditional Japanese and Chinese product (Iwasaki, 1987). Acetic acid fermentation is carried out by mixing seed vinegar with rice wine and takes 1 to 3 months. The product is ripened, filtered, pasteurized and bottled (Lai, Chang and Luh, 1980).

Rice flours and starch

Rice flour can be made from both waxy and non-waxy rices and from both raw and gelatinized rice. It is milled by rolling, pounding, shock-milling, stone-milling, milling in a lateral steel mill and wet-milling in a stone mill.

Rice starch production involves mainly wet-milling of brokens with 0.3 to 0.5 percent sodium hydroxide to remove protein (Juliano, 1984). Broken grains are steeped in alkaline solution for 24 hours, then wet-milled in pin mills, hammer mills or stone-mill disintegrators with the alkaline solution. The starch is used exclusively for human consumption, largely for baby foods and also in extruded noodles.

USE OF RICE BY-PRODUCTS

The main rice by-products from the rice milling process are the bran, broken grains and hull. Rice by-products are a renewable source of energy; they are carbon neutral and can help reduce waste and the problems associated with environmental contamination. Some processing methods and potential agro-industries are briefly described below.

Rice bran

Rice bran offers limited potential as food due to:

- the prevalence of small one-step milling machines which incorporate significant quantities of hull in the bran;
- the unhygienic conditions of the rice mill which increase microbial contamination; and
- the inability to stabilize the bran resulting in a rancid product.

The available literature, however, indicates a wide range of uses for rice bran. Bran accounts for 5 to 8 percent of the rough rice weight, while polish accounts for an additional 2 to 3 percent. Yield is influenced by the type of mill, the variety of rice and the pre-treatment (drying or parboiling) (Juliano, 1997). Stabilization is essential, considering the potential of rice bran oil for food utilization.

Extruded rice bran

With extrusion cooking, the rice bran can be heat-treated without interrupting the flow of the material since the extrusion equipment can be integrated in the processing line to produce stable rice bran. For example, an extruder which treats 500 kg per hour at 12 to 13 percent moisture content, cooking at 130°C and holding at 97° to 99°C before cooling gives a product which is stable for at least 30 to 60 days (Randall *et al*., 1985). Other extruders exist with similar conditions to stabilize the bran. The treated bran should be put into a vacuum in opaque packaging and stored in a cool place in order to increase shelf-life. This type of product can be used for breakfast formulas.

Rice bran flour

Stable rice bran can be converted to flour; it has good functional properties and can be used with other processed foods, such as breakfast cereals and other products prepared with flour materials. Wheat flour was replaced at a level of 40 and 60 percent to make muffins which were rated as acceptable (Hudson, Chui and Knuckles, 1992).

High protein bran flour

Given its hypoallergenic property, rice bran flour is a potential source of protein for infants allergic to milk or soy. The rice bran is de-fatted and sieved through a 100 mesh to obtain a light flour fraction containing 5 to 12 percent of crude fibre. Further grinding of the coarse-sieved fine (<84 µm) fraction through a senior flour mill and sieving produced flour containing 15 percent protein, 5-6 percent starch, 12-13 percent ash and 1-1.5 percent fat (Houston and Mohammad, 1966).

Bran protein concentrate

There are several processing methods to obtain bran protein. For example, in the alkali extraction process, 7.5 volumes of NaOH at pH 11 are mixed and 80 percent protein is extracted from de-fatted bran for 1 hour at 25°C; neutralization to pH 5.5 with hydrochloric acid produces precipitation containing 40 percent protein, representing 50 percent of the total protein (Chen and Houston, 1970).

Bran protein isolate

A highly purified rice protein isolate (RPI) can be obtained by heating rice bran in boiling water in the presence of a commercial heat-resistant alpha amylase (Kiriyama and Morita, 1992).

Feed

Traditionally, rice bran has been used for feed and in spite of its high fibre content, it is a high energy feed. Rice bran is more suitable for sheep and swine than cattle and chicken (Crampton and Harris, 1969). In Viet Nam, fish feed is made by mixing with a mass of cooked rice flour (made from broken rice) and passing through a pellet mill.

Ethanol

Rice bran has been used as a medium for screening Sacharomyces species for ethanol production. Shochu (Japanese alcoholic beverage) distillery waste and aromatic rice bran are used to make a fermented product with a characteristic wine-like red colour containing about 12 percent ethanol (Teramoto *et al*., 1994).

Rice bran oil

Oil is one of the most important by-products obtained from rice bran. The bran is about 20 percent oil with a high free fatty acid content (Del Rosario, 1997).

Other products

Other rice bran products with industrial potential include Inositol (a vitamin essential for babies), vitamin B concentrate, Oryzanol (antioxidant), dietary fibres, phytic acid (natural mineral chelater) and others (Del Rosario, 1997).

Broken rice grains

The rice industry trades two types of broken grains:

- Large brokens of length less than three-quarters but more than one-quarter of the average length of the whole kernel, representing 5 to 15 percent of the total milled rice.
- Small brokens or "brewer rice" of length less than one-quarter of the average length of the whole kernel, representing 5 to 15 percent of the small broken kernel.

Depending on the country standards, rice grades in the market contain 5 to 25 percent of broken kernels (IRRI, 2006). Some uses of broken rice are described below.

Beer

Small broken rice or brewer's rice is a valuable adjunct in beer production, due to the low protein and lipid content, which gives a natural aroma and flavour, and produces a clear taste. Prior to use, it is important to ensure that it is free of foreign seeds, insects, meld, soil and traces of bran (which is rich in lipids) (Yoshizawa and Kishi, 1985).

Fructose and glucose syrups

Fructose syrup can be made from broken rice using alpha-amylase, gluco-amylase and glucose isomerase. A glucose yield of 80 percent can be obtained from broken rice (90 percent starch base); it is then converted to 50 percent glucose, 42 percent fructose and 5 percent maltose. Glucose syrup production is also reported using alpha-amylase and gluco-amylase and giving a yield of 80 percent (Cheng and Chang, 1984). In both cases, broken grains are subject to gelatinization of starch prior to enzymatic hydrolysis.

Flour and pre-gelatinized rice flour

Broken grains can be milled into flours of different granulations for domestic consumption. Likewise, pre-gelatinized rice flour is produced by extrusion, pressure or steam cooking of the broken grains which are then ground into several types of pre-gelatinized rice flour (Sheng, 1995).

Feed

Broken grains have been used in many rice-producing countries for swine and poultry directly or in feed formulations.

Starch

Starch from broken rice can be produced by wet-milling with 0.3 to 0.5 percent of sodium hydroxide solution to remove protein. The broken grains are steeped in alkaline solution for 24 hours and then ground with the solution. The batter is stored for 10 to 24 hours and filtered to remove the fibre. The slurry is centrifuged to remove the starch, which is then dried. The protein can be recovered by washing and precipitation.

Maltodextrin

Maltodextrin can be made from rice flour by incubating the substrate at 80°C using heat labile amylase (Griffin and Brook, 1989).

Distilled liquors/spirits

Shochu is a Japanese liquor prepared by a non-cooking saccharafication method using raw starch degraded by enzymes from *C. paradoxa*, followed by fermentation and distillation operations (Nishimura *et al*., 1993).

Rice hull

The availability of rice hulls varies from country to country, depending on the type and size of the rice mills and their locations. Larger rice mills have more disposal problems with hulls compared to smaller village-type rice mills. Some rice mills operate for only a few months of the year, whereas others operate all year round. In most rice mills, rice hulls are separated from husked rice via aspiration, as rice hulls are lighter than husked rice. Sometimes, hulls are ground prior to piling or storage. Grinding makes it easier to transport hulls, reduces the space needed for storage and lowers transportation costs.

Rice hull as animal feed

Rice hull may be used as an ingredient in ruminant feeds; commercial feeds may contain 5 to 10 percent of ground rice hulls. Chemical, physical and biological treatments have been used to prepare rice hulls for feed:

- Physical processes include explosion-puffing at high pressure.
- Chemical treatments include alkaline solutions to increase digestibility of the dry matter.
- Biological treatment uses microorganisms and fermentation processes to grow single cell protein to increase protein and reduce fibre.

Of all cereal by-products, the rice hull has the lowest percentage of total digestible nutrients; adding a source of nitrogen can enhance hulls as feed. There are limitations to the use of rice hull as feed, including: low digestibility, peculiar size, low bulk density, high ash/silica content and abrasive characteristics (IRRI, 2006). The silica content of ash is 90 to 97 percent (Juliano, 1997).

Rice hull in agriculture uses

Rice yields can be improved with regular use of fertilizer by addition of rice husk ash. Rice hull can also serve to increase moisture retention or as a weed growth inhibitor in the soil. When the rice hull is burned, the remaining ash can be used as a mix for fertilizer or to neutralize acid soils, as is the tradition in some Asian countries and other countries where rice hull is used as a domestic fuel. Finely-ground rice hulls are a component of commercial mixed fertilizers. The rice hull prevents caking of other fertilizer components. Worms can be used in rice hull decomposition, as rice hulls can be difficult to compost.

Rice hull can also be used as substrate for seed germination, in crop growing and even in chicken hatchery to make nests for incubating eggs.

Rice hull as fuel for direct combustion and gasification

Rice husks are much more economical than rice straw for direct combustion. It is used for domestic fuel consumption and can be used to make briquettes as it improves the combustion characteristics and ease of handling. In the modern rice-milling industry, rice hulls are used as a fuel source for grain drying and parboiling. In Thailand, rice is dried in high-temperature fluidized bed dryers, and drying heat is provided by cyclonic rice hull furnaces. In Bangladesh, rice hulls are the preferred fuel for parboiling, and rice hulls are widely used for grain drying in the larger rice mills of northern India.

The gasification of rice hulls to produce combustible gas can have several objectives: direct combustion in boilers or furnaces, combustion in internal combustion engines, or production of cooking gas. Gas produced in gasifiers for use in boilers and furnaces is a technically and economically proven technology, and provides more efficient energy conversion than direct combustion of rice hulls. A limited number of small-scale rice hull gasifiers (5-20 kW) are in use in northern India (IRRI, 2006).

Other industrial uses

Other industrial uses of rice hull add higher value than agricultural uses to the products. Products that can be developed from full utilization of the rice hull include: concrete blocks, tiles and moulding, fireboard, ceramics, road-building material, sugars, ethanol, furfural and cement (Del Rosario, 1997). Rice hull ash (RHA) (35 percent) mixed with Portland cement produces compressive strength cement (DTI, 2006). Prices for RHA on the world market are approximately US$200 per tonne of ash (equivalent to US$40 per tonne of rice hulls, or US$8 per tonne of rough rice). Using RHA in the cement industry is also under consideration (IRRI, 2006).

CONSTRAINTS IN DEVELOPING THE RICE INDUSTRY

The paddy rice milling process and utilization of the main derived products and by-products represents a good alternative to rice farmers and partnerships in developing countries for the promotion and development of the small and medium rice industry to:

- add value and increase profitability;
- create employment opportunities; and
- make rice cost effective and in harmony with the environment.

However, it is important to first analyse in detail the technical and socio-economic aspects of the rice industry in question.

Different types of industry can be derived from paddy rice milling, operating in various areas:

- milled rice;
- rice processed products derived from milled rice;
- utilization of by-products; and
- paddy rice services industry (drying, parboiling, de-husking etc.).

A wide range of processed rice products and by-products can be obtained for human consumption as well as for industrial use. There is potential for further development, but improvement is required in terms of preparation, packaging and machinery usage. A wide range of tasks need to be performed, which means that such industries can create employment opportunities for all family members.

Experience in some Asian countries indicates that home industry (1-4 workers) and small industry (15-19 workers) at rural and village level are vital to the national economy, despite the phenomenal growth of the large-scale sector. Some governments encourage and support the promotion of small-scale industries through deliberate policies, for example: capital subsidies, preferential tax treatment and reservation of exclusive manufacture in the small-scale sector. In India, employment generated from small and medium enterprises is 80 percent of the total amount for manufacturing industries; in Japan and the Republic of Korea, it is 78 and 69 percent, respectively (Tamil Nadu, 2004).

In the small industry sector of developing countries, studies have indicated that organized businesses may have advantages over unorganized ones.

Constraints faced by small industries include (AGNET, 2006):

- insufficient supply of good quality raw material;
- lack of research activity at factory level;
- low level of technology;
- lack of adequate market strategies;
- inconsistent quality due to lack of facilities for quality control;
- lack of small-scale industry associations;
- lack of food standards and regulations;
- low quality packaging;
- low level of education of entrepreneurs;
- lack of finance (a common problem);
- lack of skills in small business management; and
- poor policies and incentives to promote the agro-industry sector.

CONCLUSIONS

- Rice product and by-product use in the development of small and medium industries represents an attractive technical and socio-economic challenge to stakeholders in developing countries associated with rice production, processing, research and trading.
- SMEs for rice products and by-products represent an opportunity for diversifying the food and non-food industry, including rice service industries (drying, parboiling etc.), and offer great potential for increasing income and employment opportunities.
- Rice by-products which are likely to be economically feasible include: rice hull as a fuel source, rice bran as a source of oil and broken grains as a source of flour.

RECOMMENDATIONS

- Support should be provided for the development of rice SMEs, especially in developing countries, in order to implement and improve production efficiency, quality control and safety conditions.
- Given that many products exist with the potential to be industrialized, a preliminary feasibility study should be carried out to facilitate implementation.
- In several countries, SMEs make a more significant contribution to employment generation than do large businesses; governments must, therefore, promote them and help overcome constraints through policies and strategies, including: transfer of innovative technologies and regulations; financial subsidy or assistance where possible; preferential tax treatment; and the development of adequate infrastructure.
- Transfer of technologies and financial programmes are required in order to improve the rural and village rice industry in developing countries.

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Utilisation du riz complet en vue d’assurer la promotion des petites et moyennes entreprises (PME)

Le riz usiné est le premier produit obtenu à partir du riz complet (riz paddy). Il est produit dans la plupart des pays d’Asie et dans de nombreux pays d’Afrique et d’Amérique latine. Les statistiques du commerce international indiquent que les cours du riz sont restés relativement stables ces dernières années, ce qui a affecté le développement socio-économique des pays producteurs de riz. Cette situation pourrait changer si l’on encourage les petites et moyennes entreprises à ajouter de la valeur au riz en obtenant des produits dérivés leur permettant d’accroître ainsi les revenus de la production rizicole et de créer des possibilités d’emplois.

Le présent document examine l’utilisation du riz complet du point de vue technologique. Bien qu’il soit surtout consacré à l’Asie, ses conclusions peuvent également être utiles pour les pays producteurs de riz d’autres régions. La première partie concerne les questions fondamentales concernant le riz paddy y compris ses propriétés, sa structure, sa composition et sa valeur nutritionnelle; les pratiques après récolte et la qualité et les pratiques de l’industrie traditionnelle du riz et les innovations concernant les grains de riz et les produits transformés. La deuxième partie est axée sur les technologies concernant les produits dérivés du riz et leur application à divers produits (par exemple son de riz extrudé, son, protéines destinées à l’alimentation animale isolées ou concentrées, brisures de riz, bière, sirop, aliments pour le bétail, amidon, liqueurs); et sur l’utilisation potentielle des balles de riz (par exemple, pour l’alimentation animale et comme carburant ou source d’énergie dans l’agriculture et l’industrie). Il est également question des caractéristiques et des procédures relatives au développement du secteur des petites entreprises et des principales limitations dont il faut tenir compte. Après la présentation des conclusions, des recommandations sont formulées en vue de la promotion de petites et moyennes entreprises de transformation du riz.

La utilización del arroz de grano entero para fomentar las pequeñas y medianas empresas (PYME)

El arroz elaborado es el producto primario obtenido del arroz cáscara y producido en la mayoría de los países asiáticos y en muchos países de África y América Latina. Las estadísticas de comercio internacional señalan que los precios del arroz han permanecido relativamente estancados en los últimos años, afectando así al desarrollo socioeconómico de los países productores de arroz. Esta situación podría cambiar mediante el fomento de las pequeñas y medianas empresas para dar un valor añadido al arroz y producir subproductos de éste, lo que aumentará los rendimientos derivados de la producción del arroz y creará oportunidades de empleo.

En este documento se examinan los aspectos tecnológicos de la utilización del arroz de grano entero. Pese a centrarse en Asia, sus conclusiones también resultan útiles para los países productores de arroz en otras regiones. En la primera parte se tratan cuestiones fundamentales relativas al arroz cáscara, como por ejemplo sus propiedades, composición y valor nutricional; las prácticas y la calidad post-cosecha; y las prácticas convencionales del sector del arroz y las innovaciones aplicadas al grano de arroz y los productos elaborados. La segunda parte se centra en la tecnología para subproductos del arroz y su utilización con una serie de productos, por ejemplo salvado de arroz extruido, harina de salvado, forraje proteínico aislado y concentrado, granos quebrados, cerveza, jarabe, harina, forraje, fécula y licores, así como en los posibles usos de las cáscaras de arroz, por ejemplo, para forraje y combustible/ energía, y en la agricultura y la industria. Hay un debate complementario sobre las características y los procedimientos para el desarrollo de la agroindustria a pequeña escala y sobre las principales limitaciones que debe afrontar. Por último, se presentan las conclusiones y se formulan recomendaciones para el fomento de las pequeñas y medianas empresas de elaboración de arroz.