The milestone FAO Conference on Rice in Global Markets and Sustainable Production Systems is part of the kick-off to the celebrations of the International Year of Rice. It provides a great opportunity to raise public awareness on very important subjects, namely, the key economic and production issues that will shape the world rice economy. It is an honour to make this presentation during this influential forum before many distinguished representatives from concerned governments, international and non-governmental organizations, and the private sector.

RICE – THE FIRST EVER “CROP OF THE YEAR” – COMES FULL CIRCLE
This year, 2004, is the second time that the United Nations (UN) has designated a year for rice. Thirty-eight years ago – in 1966 – rice became the first ever agricultural commodity to be declared “Crop of the Year”. When something unprecedented is suggested, some of the overly cautious will always have reservations. According to O.E. Fischnich, then Assistant Director-General of FAO, when the idea was first proposed, a number of the representatives of national governments expressed some reluctance to putting a “year tag” on any one crop. However, as the proposal was more fully discussed, as the facts established the pre-eminent position of rice as human food, and as thinking people reviewed the world food position and determined to exploit every possibility to encourage more food production, all resistance to the idea of declaring an International Rice Year disappeared (IRRI, 2003a).

The objective of International Rice Year 1966 was to encourage concerted efforts to promote rice and improve understanding of the world’s most widely eaten grain, especially in the context of its role in furthering the UN’s Freedom From Hunger campaign. The big Asian news story of 1966 was indeed hunger. In recalling that year, the Far Eastern Economic Review pointed out that 1966 brought into sudden and sharp focus the fact that the largely agricultural economies of Asia were failing to produce sufficient food to feed the region’s rapidly growing populations (Anon., 1967). Asia, once a net exporter of food, the domain of some of the world’s lushest rice bowls and wheat-lands, home to some of the world’s most skilled and industrious farmers, was a food-deficit region, literally dependent on the West to stay alive (Davies, 1967).

According to the Far Eastern Economic Review, the tragedy of the food situation in Asia was underlined by the fact that, in the year dedicated by FAO as the International Rice Year, grave shortages of rice supplies developed. Asia in 1966 had to struggle to fill its rice bowls. According to the Review, the only heartening development on the Asian food scene was the appearance of some positive signs that the official agencies responsible were willing to change their approach and give agriculture the priority that it deserved in the war on poverty.

Nevertheless, 1966 truly was an International Rice Year. Year-tagged conferences and events played a role in making it so. The release by the International Rice Research Institute (IRRI) in November of that year of IR 8 – the first modern semi-dwarf rice variety – and other achievements during those thrilling days of publicly funded international rice research left indelible marks. A year of living dangerously, teetering at the brink of mass famine, galvanized policy-makers and donors to take the bold steps that launched the green revolution (IRRI, 2003a). Whatever branded 1966 as International Rice Year, its legacies today are lasting improvements in rice farmers’ productivity and poor rice consumers’ diets. And while it cannot be said for sure that this designation was a major factor in the success that was achieved during the remainder of the twentieth century, it cannot be denied that it probably had an impact in mobilizing resources for the rice research that helped lead to those successes.
It is most appropriate that we have come full circle in declaring 2004 the International Year of Rice. Today, we have some new challenges to face – perhaps not on the mammoth scale of those of 38 years ago, but rather even more difficult from the point of view of technology. The challenges for rice farmers and researchers in 1966 were fairly straightforward. Renowned economist Dr Peter Timmer, formerly of Harvard University, points out that the task of agricultural development was much easier at that time, when the need for greater cereal output to accomplish national food security was met by new seed and fertilizer technologies, which were already in fairly advanced stages of development (Timmer, 2003). The International Year of Rice 2004 should be used to elevate the awareness (again) of key policy-makers and donors to be able to face the new (and much more complicated) challenges of the twenty-first century.

RICE: ASIA'S LIFELINE
Before discussing these challenges, it is essential that everyone present understands that the discussion is framed in the context of rice-based cropping systems in countries and areas of the world that are dominated by rice. Other speakers will list the challenges and opportunities for rice in sub-Saharan Africa, Latin America and the Caribbean, and the Near East and North Africa (all, of course, important for the people living there). The magnitude, however, pales in these regions when compared with Asia. As was pointed out during FAO’s Expert Consultation on Bridging the Rice Yield Gap in the Asia-Pacific Region (Bangkok, 5–7 October 1999), rice is the lifeline of the region where 56 percent of humanity – including about 70 percent of the world’s 1.3 billion poor people – lives, producing and consuming around 92 percent of the world’s rice (Papademetriou, 1999).

In terms of rice and its importance, there are more poor people – and starving children – in eastern India alone than there are in all of Africa! Of the most important African food crops, rice ranks a distant seventh place behind cassava, yam, maize, plantain, sorghum and millet (Hartmann, 2003). However, rice is by far the most dominant crop in Asia, where in many countries it covers half the arable land cropped.

THE CURRENT CHALLENGES
Clearly, there are two integral major challenges, for now and well into the future, involving rice in Asia. The first is the ability of nations to meet their national and household food security needs with a declining natural resource base, two of the critical resources being water and land. How the current level of annual rice production of around 545 million tonnes can be increased to about 700 million tonnes to feed an additional 650 million rice eaters by 2025 (D. Dawe, personal communication, 2003), using less water and less land is indeed the great challenge in Asia.

The second challenge – as stated so eloquently by the UN as one of its eight Millennium Development Goals1 – is the eradication of extreme poverty and hunger. Rice is so central to the lives of most Asians that any solution to global poverty and hunger must include research that helps poor Asian farmers reduce their risks and earn a decent profit while growing rice that is still affordable to poor consumers.

Scarcity of water and land
Water
As put forth by the CGIAR (Consultative Group on International Agricultural Research) Challenge Program on Water and Food, increasing water scarcity and competition for the same water from non-agricultural sectors points to an urgent need to improve crop water productivity to ensure adequate food for future generations with the same or less water than is presently available to agriculture.2 About 70 percent of the water currently withdrawn from all freshwater sources worldwide is used for agriculture; rice requires about twice as much water as other grain crops, such as wheat or maize. In Asia, irrigated agriculture accounts for 90 percent of the total diverted freshwater used, and more than 50 percent of this is used to irrigate rice (IRRI, 2001). Until recently, this quantity of water was taken for granted, but this situation cannot continue.

The reasons for the looming water crisis are diverse and location-specific, but include decreasing water quality (chemical pollution, salinization), decreasing water resources (falling groundwater tables, silting of reservoirs) and increased competition from other sectors, such as urban and industrial users (IRRI, 2003b). Though a complete assessment of the level of water scarcity in rice production is still lacking, there are signs that declining quality and availability – as well as increased competition

1 www.undp.org/mdg
2 www.waterforfood.org
and increasing costs – are already affecting the sustainability of the irrigated rice production system. By 2025, it is expected that 2 million ha of Asia’s irrigated dry-season rice and 13 million ha of its irrigated wet-season rice will experience “physical water scarcity”, and most of the approximately 22 million ha of irrigated dry-season rice in South and Southeast Asia will suffer “economic water scarcity” (Tuong and Bouman, 2002). Drought is one of the main constraints to high yield in rainfed rice production systems in both the lowlands and the uplands.

With increasing water scarcity, rice-land will shift away from being continuously flooded (anaerobic) to being partly or even completely aerobic. This shift will cause profound changes in water conservation, soil organic matter turnover, nutrient dynamics, carbon sequestration, soil productivity, weed ecology and greenhouse gas emissions. While some of these changes can be perceived as positive (e.g. water conservation and decreased methane emissions), others are perceived as negative (e.g. release of nitrous oxide from the soil and decline in soil organic matter). The challenge is to develop effective integrated natural resource management interventions which allow profitable rice cultivation with increased soil aeration while maintaining the productivity, environmental protection and sustainability of rice-based ecosystems.

To assist in meeting this challenge, the International Platform for Saving Water in Rice (IPSWAR)³ was created during an international workshop, Water-Wise Rice Production, held at IRRI (Bouman et al., 2002). IPSWAR is a mechanism to increase the efficiency and to enhance the coherence of research on water savings in rice-based cropping systems in Asia. The overarching goal is to conserve water resources, which will safeguard national and household food security and alleviate poverty.

**Land**

The lands most at threat in Asia are the fragile rainfed or upland environments where the poor are forced to use whatever resources are available to produce the food they need. As the Asian population is expected to increase from 3.7 billion in 2000 to 4.6 billion in 2025, pressure to intensify land use, in both favourable and marginal areas, will thus increase. One study (Beinroth, Eswaran and Reich, 2001) shows that most Asian countries will not be able to feed their projected populations without irreversibly degrading their land resources, even with high levels of management inputs.

In the marginal areas, intensification of land use will lead to degradation of resources through loss of biodiversity, deforestation, build-up of pest infestations, depletion of natural soil fertility and soil erosion. These changes will ultimately affect the functioning of the ecosystems. Deforestation and soil losses from upland environments also have off-site effects through changed patterns of water-flow, leading to increased frequency and intensity of flooding and consequent damage to infrastructure. Similarly, excessive use of inputs, such as chemical fertilizers and pesticides, and exploitation of groundwater in the intensive rice bowls of Asia, will likely result in resource degradation and environmental pollution, with adverse effects on human health (IRRI, 2003b).

Rice researchers have developed yield-increasing technologies for favourable environments, which have led to a massive growth in rice production through the green revolution. Had the yield of rice remained at its pre-green revolution level of 1.9 tonnes/ha, current production would have required more than double the current rice-land area. Such an expansion of rice area would have most certainly led to high environmental costs. In addition, yield improvements through better rice technologies in marginal areas have made a direct contribution to the decrease in intensification pressure in these environments.

A strategy for the future would be to further strengthen the two-pronged approach of increasing productivity in favourable environments while developing rice technologies that have minimal adverse effects on the resource base of fragile environments (IRRI, 2003b). This will involve the use of new integrative approaches that take into account resource flows, interactions and trade-offs in the use of land, labour, water and capital across the landscape for assuring farmer livelihood and resource conservation. It will be important to conduct comprehensive analyses of farmers’ livelihood strategies in fragile environments and of how these interact with the use of land resources to underpin efforts at developing suitable technologies.

**Breaking out of the poverty trap**

To illustrate the challenge of alleviating poverty, it is useful to examine a real human situation, for example,
the dilemma of Mr Sucipto, a subsistence farmer on the rainfed lowland plains of central Java in Indonesia. He uses most of his one-quarter-tonne harvest from his direct-seeded wet-season crop on his small farm to feed a large extended family. He would sell more rice if his yields were higher, but he has a lot of mouths to feed.

How can Mr Sucipto and his family (and millions like them) break out of their poverty trap? First, they are in this “trap” mainly because of the small size of their farms, which to date has not allowed them to produce much beyond their families’ needs. However, Mr Sucipto would most likely not even be adequately feeding his family were it not for the green revolution – certainly an important accomplishment. Nevertheless, even though Mr Sucipto and legions like him are not starving, they are still extremely poor!

The economist, Peter Timmer, points out that, with staple cereal prices at an all-time low in world markets, dynamic agriculture in Asia depends on diversification into commodities with better demand prospects, such as fruits, vegetables and a variety of livestock products (Timmer, 2003). To accomplish this, rice production needs to be even more efficient, freeing up resources so that many small farmers, like Mr Sucipto, can indeed consider diversifying their farms; they would also choose to use the additional resources to start or enhance full-time non-farm livelihoods.

IRRI economist, David Dawe, points out that throughout history, every country (without exception) that has become wealthy has removed most of its population from agriculture. It is, therefore, necessary to get some people out of rice farming, while still keeping rice prices low in order to assure household food security for the hundreds of millions of rural and urban poor who will still be eating the staple. To accomplish this, a new breed of rice farmer must emerge in Asia, capable of taking advantage of a more efficient, productive and profitable rice industry made possible by the exciting new technologies being developed by rice research.

One last point must be made before moving on to the array and the importance of those new technologies. The terms “national food security” and “household food security” are used in this paper, and the difference should be explained. Dr Dawe defines national food security, which was achieved for many Asian nations by the green revolution with its new seed and fertilizer technologies, as the ability of a country (in some sense) to either produce or import enough grain or food to meet the average needs of its population. However, a country can achieve national food security and obviously still have a large part of its population poor and not enjoying what we call household food security, which is (as defined by Dr Dawe) providing poor families with enough income to buy the food that they need. With household food security, a family can lead a healthy, active life with no worry about where the next meal is coming from.

**TECHNOLOGICAL INNOVATION IS ESSENTIAL FOR PROGRESS**

It is safe to say that almost everyone agrees that technological innovation is essential for human progress. Indeed, it has been at the heart of development over the centuries. From early farmers’ selection of seeds to the green revolution, from the first use of penicillin to the widespread use of vaccines, and from the printing press to the computer, people have devised tools for raising agricultural productivity, improving health, and facilitating learning and communication.

Building human capacities and economic growth are integrally linked with technological innovation: you cannot have one without the other. Technological innovation is a means to human development because of its impact on economic growth through the productivity gains it generates. And conversely, human development is an important means to the development of new technologies.

The assessment of the United Nations Development Programme (UNDP, 2001), as articulated in its *2001 Human Development Report*, is that technology deserves more attention than ever. Certainly, just as the technological breakthroughs of the past have improved human health and nutrition, expanded knowledge and stimulated economic growth, the genetic, molecular and digital wonders of the modern world will only accelerate how we can use technology to alleviate, if not eradicate, poverty and to meet the challenges posed by water scarcity, land degradation and other problems.

There is no doubt that technology will play a crucial role in helping a substantial percentage of the poor people currently tilling millions of tiny rice farms in Asia break out of the poverty trap. This conviction is based on what green revolution technology has already accomplished in rice on the continent over the last 25 years.

Certainly, increased production and lower prices of rice across Asia have been the most important results of the higher yields that rice research and new farming tech-
Technologies have made possible. Around 1,000 modern varieties (approximately half the number released in 12 countries of South and Southeast Asia over the last 40 years) are linked to IRRI germplasm, i.e. a very large impact. Modern varieties and the resultant increase in production have increased the overall availability of rice and have also helped to reduce world market rice prices by 80 percent over the last 20 years. Poor and well-to-do farmers alike have benefited directly through more efficient production that has led to lower unit costs and increased profits. Poor consumers have benefited indirectly through lower prices. This has brought national food security to China and India, not to mention Indonesia and other countries. However, further increases in output and even lower prices continue to be needed for many poor families to realize household food security.

Some of the technologies IRRI and its partners are using to meet the challenges of the twenty-first century are discussed below. Some are already benefiting farmers, while others promise results in the near (<5 years) and distant (5–15 years) future.

**Dawn of tropical hybrid rice in Asia**

After more than 20 years of research, tropical hybrid rice is becoming an option for many Asian farmers. By exploiting the phenomenon of hybrid vigour (FAO, 2003a), hybrid rice varieties yield between 1 and 1.5 tonnes/ha (15–20 percent) more than the best semi-dwarf inbred varieties grown under irrigated conditions. The vigorous and more active root system of hybrid varieties also enables them to tolerate moderate stresses caused by salinity and drought due to limited irrigation water.

This technology has already demonstrated great potential for increasing rice production in China, where 15 million ha (50 percent of the total rice area) are planted to hybrid rice varieties (Virmani, Mao and Hardy, 2003). In tropical Asia, hybrids have started showing their potential in India, Viet Nam, the Philippines, Bangladesh and Indonesia, where a total of about 1 million ha were planted to hybrid rice varieties in 2003 (S.S. Virmani, personal communication, 2003).

This technology clearly helps rice farmers to increase their yields, productivity and profitability by using less land and water, and enables them to opt for crop diversification to increase their income. An associated seed production technology has helped to develop a seed industry in Asia, which in turn has contributed to increasing rural employment opportunities.

Within the next few years, the hybrid rice area in tropical Asia should increase significantly due to the efforts of countries such as the Philippines, where an ambitious hybrid rice programme aims for its farmers to be growing 600,000 ha by 2005 (Aguiba, 2003).

**New plant type: foundation for higher-yielding rice plants**

Parallel to the development of hybrid rice, IRRI and colleagues in national research programmes have achieved another important success: the new plant type (NPT). With the NPT, the objective is to increase both the total biomass and the harvest index of the plant, which it is hoped will increase yield potential by about 20 percent over current modern varieties. In yield trials, the top-performing tropical NPT line has produced 10.2 tonnes/ha, which is very close to the best yields of any post-green revolution varieties.

NPT lines have been distributed via nurseries of the International Network for Genetic Evaluation of Rice (INGER) to interested countries. National programme researchers are now evaluating these very best lines under local conditions. Three NPT varieties are outyielding popular modern varieties in farmers’ fields by 1 tonne/ha in China.

The evidence accumulated by IRRI suggests that the yield barrier of 10 tonnes/ha is probably a fundamental obstacle rooted in the bioenergetics of 100-day rice crops growing in the tropics. A radical solution is therefore needed and NPTs will have a major part to play in breaking this yield barrier: NPTs have many properties (mechanical strength to support higher yields and high leaf nitrogen content for building higher grain yields) that could make them part of the foundation of the higher-yielding lines of the future. The improved NPT lines have equal contributions from both the *indica* and *japonica* subspecies, resulting in a significant increase in genetic diversity of the elite breeding lines from IRRI. The NPT lines will be valuable parents for achieving higher heterosis in hybrid rice varieties.

**Transferring C4 maize genes to C3 rice to save water and fertilizer**

As part of the quest for higher yield potential in rice, the link between photosynthesis, yield and radiation-use efficiency (RUE) must be examined. According to some scientists, the upper yield limit of rice with its conventional photosynthetic pathway will go only halfway to
the goal of increasing rice yield by 50 percent by 2050. Improved crop photosynthesis would then seem essential. One proposal for increasing rice’s RUE is to incorporate the high C4 photosynthetic capacity of a crop such as maize into rice, which is a less photosynthetically efficient C3 cereal (Sheehy, Mitchell and Hardy, 2000).

Making the photosynthetic pathway of rice resemble that of maize would require a long-term genetic engineering project (10–15 years) to introduce genes for enzymes of the C4 pathway and for leaf anatomy. If accomplished, the benefits would be enormous across the rice ecosystem spectrum. A C4 rice plant would yield the same as a C3 with half the transpirational water loss. It would also require significantly less N fertilizer, thus providing for a cleaner environment. In irrigated rice, yield potentials would rise significantly, enabling poor farmers to produce enough additional income to break out of that poverty trap.

In drought-prone ecosystems (rainfed lowland and upland rice), yields could be maintained or increased with less water and less fertilizer, especially when coupled with the predicted rising atmospheric concentration of carbon dioxide that is associated with future world climate change. Farmers living at the margins in these ecosystems would see improvements in yield and yield stability. It would be a revolution in rice farming.

**Molecular breeding for dealing with complex traits**

There has been great success in backcross breeding for simply inherited traits. There are also tremendous amounts of “hidden” genetic diversity for many complex traits, particularly for yield and abiotic stress tolerances, in the primary gene pool of rice – much of which will be more easily “found” with the wealth of information coming out of the sequencing of the rice genome (Cantrell and Reeves, 2002). The new International Network for Rice Molecular Breeding (INRMB), devised by Zhikang Li, an IRRI molecular geneticist based at the Chinese Academy of Agricultural Sciences, is attempting to fully exploit the genetic diversity in the germplasm collections preserved in rice gene banks by integrating gene discovery and allele mining with rice improvement.

INRMB has a comprehensive strategy involving marker-aided and backcross breeding and improved phenotypic selection. We believe this strategy will contribute to discovering and exploiting the hidden diversity. Currently, large-scale gene/QTL (quantitative trait loci) discovery, allele mining (see below) and marker-aided pyramiding of complex traits are in progress in China and at IRRI. By sharing this information and materials with participating national agricultural research and extension systems (NARES), the network will aid in the development of elite rice varieties in a shorter time than could be achieved through more conventional breeding approaches.

**Allele mining for efficient use of natural variation**

Regarding allele mining, an operation has been set up at IRRI’s International Rice Genebank (Leung, Hettel and Cantrell, 2002). The bank contains more than 102,000 distinct accessions with a wide range of untapped traits for variety improvement. With the rice genome sequence available, it is possible to identify important loci and screen the gene bank collection for novel alleles at those loci to find traits, for example, related to disease resistance. The challenge is to find genes and mechanisms to provide broad-spectrum resistance to rice pathogens, such as blast and bacterial blight. This will benefit farmers by avoiding the boom and bust cycle caused by disease epidemics. Promising results are due soon. For example, in the fight against blast, five known defence genes have been put together in a rice cultivar from China, resulting in good resistance across locations, presumably because of resistance to multiple races of the pathogen.

**Meeting the water crisis head on with aerobic rice**

To meet the water crisis head on, valuable gains can be achieved by growing rice with less water. Traditionally, producing 1 kg of rice requires between 3,000 and 5,000 litres of freshwater. It is necessary to develop a fundamental approach for reducing the water requirement of rice to significantly below this level. Why not create an “aerobic rice” that could be treated like other irrigated crops?

Within the next 4 to 5 years, it will be possible to develop an “aerobic” rice plant for the Asian tropics that grows similarly to rice plants being grown in irrigated upland rice fields in Brazil. An aerobic rice working group, involving breeders, physiologists and water and soil scientists, is striving to overcome the many difficulties involved in taking rice out of its natural environment. By developing a completely new management system, the new aerobic rice should be able to yield 6 to 7 tonnes/ha using only half the water.

Aerobic rice will also help close the yield gap in marginal rainfed environments. Initial results in the
Philippines suggest that aerobic rice outperforms lowland rice under rainfed conditions. It is hoped that similar inroads can be made in the rainfed uplands.

**Developing resilient varieties for drought-prone environments**

In addition to aerobic rice, drought tolerance is being enhanced on other fronts. Molecular geneticists and physiologists are producing an enormous amount of information in order to develop resilient rice varieties for drought-prone environments. Over the next few years, significant progress is expected in our understanding of the genetic basis of variation in drought tolerance among rice varieties. Novel introgression lines between drought-susceptible lowland cultivars and low-yielding but drought-tolerant upland varieties have been developed. Genomics and bioinformatics tools are being used to identify the exact genes that confer this tolerance. Breeders will then use markers to locate these genes to improve drought tolerance in agronomically adapted varieties. It is expected that multiple genes and alleles will be important in different stress scenarios.

IRRI has developed a broad range of introgression stocks to be used for this gene discovery. Within the next few years, these products are expected to reveal key genes and superior alleles for breeders to use in improving yield under drought conditions. Recently, IRRI hosted a drought workshop during which specialists developed collaborative research agendas. Much of the new information on drought tolerance has been captured in a new IRRI book, *Breeding rice for drought-prone environments* (Fischer et al., 2003).

**Integrated pest management to protect the environment**

Another technology that will maintain and even enhance yields while protecting the environment – and at the same time allow farmers to save their scarce and precious resources for other endeavours – involves integrated pest management (IPM). Hundreds of millions of farmers in Asia still overuse pesticides, despite the emergence of viable alternative strategies for pest control. Not only do misapplied pesticides pollute the environment and threaten the health of farmers and their families, they set the stage for secondary pest infestations that can cause devastating crop losses (IRRI, 2003c).

At IRRI, patterns of insecticide use have been studied and it has been found that spraying early in the crop cycle is unnecessary. Farmers often spray to eliminate visible leaf-feeding worms that do not cause yield loss. Worse, spraying disrupts the diverse ecology of the field, paving the way for pest infestations. Researchers, therefore, came up with a way to motivate farmers to change their spraying practices.

A Viet Nam study offers valuable lessons, and findings were expressed in one simple rule: “Don’t spray for the first 40 days.” A media campaign was launched to deliver the message to farmers, stressing the cost savings and health benefits of reduced spraying: in the test area of 21,000 households, after 18 months, a 53 percent reduction was recorded in the number of insecticide applications – with no effect on yields! Many farmers reduce input costs by between US$30 and US$50 per season (the equivalent of a month’s income in Viet Nam). Under-scoring the significance of this work, the project received the St Andrews Prize for the Environment from St Andrews University (Scotland, United Kingdom) in 2002 and the International Green Apple Environment Award from the United Kingdom-based Green Organization in 2003 (IRRI, 2003c).

IRRI researchers and collaborators achieved another notable IPM success in China’s southwestern province of Yunnan. In what the *New York Times* called “one of the largest agricultural experiments ever” (Yoon, 2000), it was found that intercropping rows of different varieties of rice can almost completely control devastating rice blast (Zhu et al., 2000). Some farmers there were already using this technique, albeit in a haphazard way. Several variations of the concept were scientifically tested and improved.

Findings are now being disseminated, confident that the practice not only reduces farmers’ reliance on chemical pesticides, thereby protecting the environment, but also improves yields and incomes to give farmers the options they need to break out of the poverty trap. Word-of-mouth is already leading to the technique’s wide adoption in China.

**Nutrient-use efficiency for intensive systems**

New inroads into nutrient-use efficiency in intensive rice-farming systems are soon to make an impact. Collaborative research in the Irrigated Rice Research Consortium has found that inefficient and unbalanced

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4 www.irri.org/irrc/default.asp
fertilizer use is widespread among Asia’s rice farmers and millions of them may need to change their management practices and adopt new technologies to increase productivity and sustain the soil and water resource base. These changes promise substantial increases in their yields – and their incomes – which will in turn give them new options for the future.

An approach called site-specific nutrient management (SSNM) is central to this effort. This tactic has been successfully tested over the last 6 years in more than 200 on-farm experiments across Asia. On average, farmers’ yields and profits increased by 10 to 15 percent with improved nutrient management. The concept is being simplified in collaboration with researchers, extension personnel and farmers in pilot villages in six Asian countries with supplemental support from the Potash and Phosphate Institute in Singapore.

Information on SSNM is being disseminated through a comprehensive practical guide (Fairhurst and Witt, 2002) and a new book that summarizes SSNM research conducted since 1994 (Dobermann, Witt and Dawe, 2004). Training materials and software are also being released for a support system to aid farmers in making the right decisions regarding their nutrient applications.

Biofortification to boost rice’s nutrient content

Finally, household food security is only truly achieved when, in addition to being available in sufficient quantity, the food is also of good quality. Although rice supplies adequate energy in the form of calories and is a good source of thiamine, riboflavin and niacin (FAO, 2003b), it is lacking as a source of vitamin A and other critical vitamins, iron, zinc and other micronutrients and amino acids that are essential to human health, especially the health of children. The nutrient content of rice can be improved substantially by using both traditional selective plant breeding and new biotechnology approaches.

IRRI is a major player in the CGIAR Challenge Program, Harvest Plus, which is seeking to reduce the effects of micronutrient malnutrition by harnessing the power of plant breeding to develop staple food crops that are rich in micronutrients, a process called biofortification. In this effort, rice will involve more scientists and research teams than any other crop. Swapan Datta, IRRI plant biotechnologist and the rice crop leader of Harvest Plus, has been active in research on enhancing micronutrient levels in rice through genetic engineering and leading the development at IRRI of tropical varieties of vitamin A-enriched Golden Rice (Datta et al., 2003). It was only in early 2001 that the first seed samples were delivered to IRRI by Prof. Ingo Potrykus, the German co-inventor of this genetically modified rice, which could save half a million children each year from irreversible blindness (Nash, 2001).

Dr Datta’s team of scientists has bioengineered several Asian indica varieties with genes for beta-carotene biosynthesis. Selected lines, including genotypes of IR 64, show expression of beta-carotene, the precursor of vitamin A (Datta et al., 2003). Non-antibiotic and marker-free IR 64 Golden Rice is now being evaluated in the IRRI greenhouse, which will be used for evaluating agronomic performance in 2004. Dr Datta says that a long programme of safety and bioavailability tests means that the release to farmers of indica Golden Rice is probably still 4 to 6 years away.

Also, IRRI and its collaborators in Japan have introduced an iron-enhancing ferritin gene to indica rice in such a way that it expresses itself in the rice endosperm; after polishing, the rice grains contain three times more iron than usual (Vasconcelos et al., 2003). Dr Datta says this is the most significant increase in iron ever achieved in an indica rice variety and it could have significant benefits for the 3.5 billion people in the world who have iron-deficient diets.

IRRI’S ROLES IN THE “GENOMICS ERA”: PRODUCING KNOWLEDGE THROUGH NEW TECHNOLOGIES AND BRINGING THE BENEFITS TO THE POOR

In conclusion, IRRI has a special role to play in bringing to the poor the benefits of many of the technologies discussed above. The sequencing of the rice genome, followed by the discovery of the functions of individual genes and combining them to accelerate crop improvement, is revolutionizing rice science (Cantrell, 2002). Entry into this genomics era has fomented new interest in rice from the private sector. Critics fear that private ownership of portions of the rice genome will commercialize the crop in a way that subverts the right of farmers to grow the traditional varieties their ancestors developed over the millennia, as well as the improved varieties that publicly funded research institutions have bred and distributed as public goods over the past few decades. Insisting that rice must remain wholly within the public
domain, they roundly condemn both private research and public-private research partnerships. But they remain silent on the question of how cash-strapped public research institutions, such as IRRI, can maintain momentum without private-sector participation and the patents that corporations need to protect their investments. Wholly public ownership of the fruits of rice research would require steadfast commitment to public support for that research – sadly lacking at present (Cantrell, 2002).

IRRI’s roles as a producer of knowledge and a catalyst in technology development and transfer among various public institutions (and increasingly between the public and private sectors) are important as never before for assuring strength in both sectors and maintaining a balance (Leung, Hettel and Cantrell, 2002). For example, one approach advocated is the formation of the International Rice Functional Genomics Consortium as a means to engage both developed and developing nations in contributing to the functional characterization of all agronomically important genes in rice. Active participation by developing countries will ensure access to the new science in the future.

As illustrated in this presentation, IRRI’s key assets are a wealth of genetic resources and collective know-how across biological disciplines that are directly relevant to improving rice-based production systems, which will result in enhancing national and household food security, thus alleviating poverty across Asia and the Pacific. There has been investment in research infrastructure to provide training and complementary support to NARES research partners and IRRI has the technical expertise to be a strong research partner with advanced research institutes (ARIs).

IRRI has also adopted a policy on intellectual property rights that adheres to the institute’s principles and mission, while allowing collaboration with the private and public sectors to bring in new science to benefit the poor. To capitalize on the advances being made in rice science research, IRRI can serve as the unbiased “broker” between the rice improvement institutions in the developing world and the ARIs.

The IYR slogan, “Rice is Life”, applies perfectly to Asia today and, conversely, the Asia of the future has no life without rice.

REFERENCES


www.iris.irri.org/IRFGC/


INTRODUCTION

The lack of food security for a large proportion of the African population continues to exacerbate poverty and malnutrition. High population growth, the effects of HIV (human immunodeficiency virus) on the productive labour force, the degradation of the environment, poor agricultural development support services and lack of enabling economic policy environment have all aggravated the situation. Rice has great potential and can play a critical role in contributing to food and nutritional security, income generation, poverty alleviation and socioeconomic growth in Africa. It is an important food crop in many African countries and is increasingly preferred over many traditional foods, such as sorghum, millet and most root and tuber crops. It is the staple food crop in Côte d’Ivoire, the Gambia, Guinea, Guinea-Bissau, Liberia, Madagascar, Mauritania, Senegal and Sierra Leone. In most countries, rice supply cannot keep up with demand. Consumption demand has grown rapidly over the last two decades and is now more than 6 percent per annum, amounting to over 10 million tonnes of milled rice per year (Figures 1 and 2). In West Africa alone, FAO projected that rice imports would rise to 4 million tonnes per year by 2000, drawing approximately US$1 billion from foreign exchange earnings. This increase is due to both population growth (2.6 percent per year) and the increasing share of rice in the diet of African populations (1.1 percent per year); rice consumption in 1998 was 30 kg per caput per year (FAO, 1999), mainly as a result of rapid urbanization (Snrech, 1994). Urban rice consumers, faced with a relative increase in the rice price, prefer to maintain their consumption level (at the expense of other categories of goods), rather than shifting to other cereals. This is most probably due to the ease of preparation and the difference in time perception between urban and rural families. The vast majority of rice in Africa is rainfed and grown by smallholder farmers, a disproportionate number of whom are women. Growth in demand is creating opportunities for small-scale producers.

The production of rice in sub-Saharan Africa has steadily increased since the 1970s, reaching almost 7 million tonnes of milled rice by the end of the last decade. The increase in rice production is due to: expansion in area (70 percent) and yield increase (30 percent) (Fagade, 2000; Falusi, 1997). The gap between rice demand and regional supply is increasing and was about 4 million tonnes of milled rice for sub-Saharan Africa as a whole in 1998 (Figure 2). Nigeria was the major rice importer with almost 1 million tonnes in 1999/2000 (Mbabaali, 2000).

The social interest in developing regional rice production goes further than import substitution. As mainly resource-poor farmers grow rice integrating a wide range of other agricultural activities, rice research and development can be considered an entry point for the development of the agricultural sector as a whole. Thus, rice research and development can be seen as a catalyst, reducing production risks, averting natural resource degradation, enhancing food security and income and contributing to poverty alleviation.

The objective of this paper is to provide an overview of the challenges and technical opportunities in developing rice-based systems for food security and poverty alleviation in sub-Saharan Africa. The data presented relate mainly to West and Central Africa.

RICE ECologies IN WEST AND CENTRAL AFRICA

The potential for rice development in West and Central Africa is largely determined by the agro-ecological conditions in which rice can be produced. Rice is characterized by its plasticity which allows it to grow in almost any biophysical environment in West and Central Africa. Rice is grown in a whole range of agro-ecological zones...
FIGURE 1
Per caput rice consumption in West and sub-Saharan Africa


FIGURE 2
Milled rice production and imports in West Africa compared to the rest of sub-Saharan Africa (SSA)

from the humid forest to the Sahel (Figure 3). The total rice area in West and Central Africa amounts to more than 4 million ha (FAO, 1999). Within these regional agro-ecological zones, five main rice-based systems can be distinguished with respect to water supply and topography in sub-Saharan Africa (Windmeijer, Duivenbooden and Andriesse, 1994):

- Rainfed upland rice on plateaus and slopes;
- Lowland rainfed rice in valley bottoms and floodplains with varying degrees of water control;
- Irrigated rice with relatively good water control in deltas and floodplains;
- Deep-water, floating rice along river beds and banks; and
- Mangrove swamp rice in lagoons and deltas in coastal areas.

The three main rice ecologies across West and Central Africa are the rainfed uplands, the rainfed lowlands and the irrigated systems (Table 1). These ecologies can be found across agro-ecological zones. A distinction is made between irrigated systems in the desert margins of the Sahel and those in the savannah or humid forest zones. The upland rainfed rice-based systems cover the largest area (44 percent), mainly in coastal areas in the humid and subhumid agro-ecological zone. The rainfed lowland systems are the second most important in terms of surface area, accounting for 31 percent of the total rice cultivated area; third are the irrigated rice-based systems (12 percent). Deep-water and mangrove rice systems are relatively unimportant in terms of surface area.

Using average rice yields of 1 tonne/ha in the uplands, 2 tonnes/ha in the lowlands, 3 tonnes/ha in irrigated areas in the savannah/humid zone and 4.5 tonnes/ha in irrigated areas in the Sahel, it is possible to make estimates of production figures (Table 2). Rainfed rice production systems are still predominant, providing more than half the total production. Rainfed lowland systems provide 36 percent of the production, followed by rainfed upland (25 percent). The irrigated systems account for 28 percent of production, with 22 percent in the Sahelian zone. Irrigated systems in the savannah and humid forest zone are rather minimal in terms of rice production.

The major rice ecologies present various commonalities, such as weed and pest pressure and soil fertility decline. In addition, interlinkages exist between ecologies.
### TABLE 1
Share of rice ecologies in rice planted areas by country

<table>
<thead>
<tr>
<th>Country</th>
<th>Total area ('000 ha)</th>
<th>Share of national rice area (%)</th>
<th>Year of reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mangrove swamp</td>
<td>Deep-water floating</td>
</tr>
<tr>
<td>Mauritania</td>
<td>23</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Senegal</td>
<td>75</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Mali</td>
<td>252</td>
<td>0</td>
<td>64</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>25</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Niger</td>
<td>28</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Chad</td>
<td>31</td>
<td>0</td>
<td>92</td>
</tr>
<tr>
<td>Cameroon</td>
<td>15</td>
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</tr>
<tr>
<td>Gambia</td>
<td>19</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Guinea-Bissau</td>
<td>65</td>
<td>49</td>
<td>0</td>
</tr>
<tr>
<td>Guinea</td>
<td>650</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>356</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Liberia</td>
<td>135</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Côte d'Ivoire</td>
<td>575</td>
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<tr>
<td>Ghana</td>
<td>81</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Togo</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Benin</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nigeria</td>
<td>1 642</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>West Africa (total)</td>
<td>4 011</td>
<td>4</td>
<td>9</td>
</tr>
</tbody>
</table>

*Source: WARDA, 1997 and also 1996 data provided by FAO.*

### TABLE 2
Estimated share (%) of rice production by ecologies and by country

<table>
<thead>
<tr>
<th>Country</th>
<th>Mangrove swamp</th>
<th>Deep-water floating</th>
<th>Irrigated Sahel zone</th>
<th>Savannah/humid zone</th>
<th>Rainfed lowland</th>
<th>Rainfed upland</th>
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<tbody>
<tr>
<td>Mauritania</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>Mali</td>
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<td>35</td>
<td>50</td>
<td>0</td>
<td>50</td>
<td>3</td>
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<td>0</td>
<td>47</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>Niger</td>
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<td>18</td>
<td>82</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
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<td>82</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Cameroon</td>
<td>0</td>
<td>0</td>
<td>99</td>
<td>0</td>
<td>66</td>
<td>8</td>
</tr>
<tr>
<td>Gambia</td>
<td>14</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>26</td>
<td>17</td>
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<tr>
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<td>0</td>
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<td>0</td>
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<td>17</td>
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<tr>
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<td>7</td>
<td>0</td>
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<td>Sierra Leone</td>
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<td>89</td>
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<td>2</td>
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<tr>
<td>Ghana</td>
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<td>0</td>
<td>0</td>
<td>31</td>
<td>21</td>
<td>48</td>
</tr>
<tr>
<td>Togo</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>30</td>
<td>66</td>
</tr>
<tr>
<td>Benin</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>8</td>
<td>81</td>
</tr>
<tr>
<td>Nigeria</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>27</td>
<td>53</td>
<td>17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4</strong></td>
<td><strong>5</strong></td>
<td><strong>22</strong></td>
<td><strong>6</strong></td>
<td><strong>36</strong></td>
<td><strong>25</strong></td>
</tr>
</tbody>
</table>

*Note: Average rice yields used for % calculation:
upland: 1 tonne/ha; lowland: 2 tonnes/ha; irrigated, savannah/humid zone: 3 tonnes/ha; irrigated, Sahel zone: 4.5 tonnes/ha.
Source: WARDA, 1997 and also 1996 data provided by FAO.*
(e.g. water or nutrient flow from upland to lowland), influencing the ecological sustainability of farmland. In response to this challenge, The Africa Rice Center (WARDA) has developed the concept of the upland-lowland continuum along a toposequence, based on watertable depth (WARDA, 1989). Furthermore, interlinkages can blur the borderline between ecologies, like the hydromorphic fringe between the upland and lowland along the continuum. Another fuzzy transition exists between rainfed and irrigated lowland. A water-management continuum, ranging from strict rainfed to fully irrigated lowland, can be distinguished, and it may evolve depending on investments in water control measures (Figure 4).

CONSTRAINTS, OPPORTUNITIES AND CHALLENGES
Lançon and Erenstein (2002) calculated that with an annual per caput rice consumption growth of 1 percent and population growth of 2.5 percent, total rice consumption in West Africa would reach 10 million tonnes in 2010 and 15 million tonnes in 2020. There are three major options for increasing rice production:

- area expansion;
- increase in cropping intensity (number of crops per year from the same area); and
- yield increase (produce per unit area).

The opportunities for rice production development depend to a large extent on the biophysical and socio-economic environments. The challenges for area expansion, increase in cropping intensity and yield increase vary widely by ecology. The following sections highlight farmers’ major biotic and abiotic constraints at plot level, and institutional/organizational constraints at farm, community and regional levels with specific attention to the divergences between the major rice ecologies. Combined with specific ecological opportunities, these constraints determine the major challenges for rice research and development.

Upland ecology
Upland rice is to a large extent produced by subsistence-oriented farm households representing only part of the total cropped area and which do not use external inputs,
mainly due to high production risk and poverty. Rice yields in upland systems average about 1 tonne/ha; however, these figures hide large differences between farms. Within a given region or village, differences in cropped area and yields between farms may vary tenfold, partly because of differences in the quality of the land, but they are also as a result of differences in management practices (time of sowing, weed control etc.).

Weed competition is indeed one of the most important yield-reducing factors (Johnson, 1997), followed by drought, blast, soil acidity and low soil fertility. Farmers traditionally manage these stresses through long fallow periods. Population growth and resulting pressure on the land has led to increasing reduction of fallow periods and extension of cropped areas, often towards the more fragile upper parts of the slopes. In the rainfed uplands, slash-and-burn agriculture and reduced fallow periods have aggravated weed pressure and general decline in land quality through soil erosion (Oldeman and Hakkeling, 1990) and soil nutrient depletion, known as “soil mining” (Van der Pol, 1992). The increase in population pressure aggravates the situation, resulting in low and unstable rice yields. Lack of capital limits the use of external resources and intensification of the system. Weed competition further reduces labour productivity and increases the risk of crop failure. Farmers traditionally use long-duration rice cultivars that further undermine the fragility of the system and limit the cropping intensity. Declining productivity and incomes feed the cycle of poverty and environmental destruction (Cleaver, 1993; Cleaver and Schreiber, 1994).

The major challenges for rice research and development in the upland ecology relate to sustainable stabilization and intensification of upland rice production;
there is good opportunity for increasing yields and possibly the cropping intensity. Improved varieties with high-yielding capacity under low-resource input conditions are an underexploited potential. However, low-cost complementary soil fertility management practices will have to be introduced, for example, crop rotation with legumes to maintain or improve soil quality, avoid soil nutrient mining and enhance sustainability. With short-duration varieties, it might be possible to introduce rice-legume cropping systems within the same cropping season if rainfall is adequate. Given the complexity and diversity of the upland rice systems, technologies will have to be adapted and fine-tuned in situ. This will require new approaches for farmers to play more important roles in technology development and for effective interaction between researchers and farmers to develop appropriate technologies.

**Technical opportunities**

Given the fragility of the upland rice system, technologies are urgently needed to reduce degradation of the fragile resource base and ensure sustainable stabilization of the system.

WARDA’s breakthrough in developing New Rice for Africa (NERICA) based on crosses between African rice (*O. glaberrima*) and Asian rice (*O. sativa*) provides an exciting opportunity for farmers to stabilize and intensify low-input upland systems. NERICAs tend to have better resistance to most African stresses including weeds and drought. They have high-yielding potential and generally outyield local varieties, under both low- and high-input conditions (Jones and Wopereis-Pura, 2001). Moreover, compared to local varieties, NERICAs generally have a much shorter growing cycle (90 to 110 days), providing the opportunity to produce food during the hungry season. Moreover, short-duration NERICAs allow rice farmers to adjust their agricultural calendar to climatic variation (Jones and Wopereis-Pura, 2001). The early-maturing NERICAs have a comparative advantage over local varieties with respect to demand for labour. Labour-saving technologies can motivate farmers to concentrate agricultural activities in a more limited area, allowing the most fragile areas to revert back to natural vegetation. Resource degradation will be reduced, yields and income will be stabilized and labour productivity and income will be increased. NERICAs may also help stop expansion of cultivated land areas, because double-cropping of NERICAs is possible under sufficient rainfall.

The idea is, however, not to promote the replacement of local varieties by NERICAs. Rather, WARDA’s strategy is to integrate NERICAs into the existing varietal portfolio of farmers. Indeed, in 1997 WARDA set up a participatory variety selection (PVS) approach, with farmers selecting varieties from rice gardens with large numbers of local and modern *O. sativa* and NERICA varieties (Figure 5). The PVS-approach is a 3-year programme allowing farmers to test and evaluate their own selected varieties under their site-specific conditions and according to their needs. The most promising varieties are then proposed to the national release committee (Table 3). This approach is an example of how farmers can be effectively involved early in the research and development process of new technologies. A study conducted by Diagne et al. (2001) shows that the PVS approach leads to increased biodiversity, as the number of varieties grown per farmer can be increased.

**Irrigated ecology**

Irrigation systems include dam-based irrigation, water diversion from rivers and pump irrigation from surface

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**TABLE 3**

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Countries</th>
<th>Agronomic characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAB 56-50</td>
<td>Burkina Faso, Côte d’Ivoire, Gambia, Guinea-Bissau, Liberia</td>
<td>Blast resistance, drought tolerance, high yield</td>
</tr>
<tr>
<td>WAB 56-125</td>
<td>Burkina Faso, Côte d’Ivoire, Nigeria</td>
<td>High yield</td>
</tr>
<tr>
<td>WAB 56-104</td>
<td>Côte d’Ivoire, Liberia</td>
<td>High yield</td>
</tr>
<tr>
<td>WAB 56-39</td>
<td>Burkina Faso</td>
<td>High yield</td>
</tr>
<tr>
<td>WAB 96-1-1</td>
<td>Côte d’Ivoire, Cameroon, Guinea-Bissau, Liberia, Sierra Leone</td>
<td>Weed competitiveness, high yield</td>
</tr>
<tr>
<td>WAB 384-B-B-3-1-2</td>
<td>Cameroon</td>
<td>High yield</td>
</tr>
<tr>
<td>WAB 36-2LFX</td>
<td>Nigeria</td>
<td>High yield</td>
</tr>
<tr>
<td>WAB 36-34-FX</td>
<td>Nigeria</td>
<td>High yield</td>
</tr>
</tbody>
</table>
water or tubewells. Major differences in constraints, opportunities and challenges exist between irrigated rice ecologies in the Sahel and in the humid forest and savannah zones.

Average farmers’ yields in the Sahel are around 4 to 5 tonnes/ha per season, with potential yields varying from 6 to 11 tonnes/ha per season, limited by solar radiation and temperature only. The potential yield gains from improved crop and resource management are, therefore, tremendous. In the Office du Niger in Mali, average yields have increased over the last 15 years from 2 to almost 6 tonnes/ha. Only 10 percent of the area under irrigation is double-cropped, because of extreme temperatures in both hot and wet seasons. The relatively demanding cropping calendar leaves little room for delays in activities, and mechanization is relatively widespread. However, labour remains a limiting factor and about half of the rice grown in the Sahel is direct-seeded. African rice gall midge (AfrRGM), rice yellow mottle virus (RYMV) and blast are the major pests found in the irrigated rice ecosystems.

Moving south into the savannah and humid forest zones, schemes become smaller, they are mainly transplanted and located along major roads and near urban centres. Compared to the Sahel, rice productivity in the savannah and humid forest systems is less constrained by temperature extremes, but potential yields are lower, ranging from 5 to 8 tonnes/ha per season, as a result of lower solar radiation levels. Actual yields are around 3 tonnes/ha per season, indicating considerable scope for yield gains.

Still, substantial investments have already been made in irrigation infrastructure, especially in the Sahel. The development, maintenance and rehabilitation of the existing infrastructure provide concrete opportunities to capitalize on these earlier investments. This is adequately illustrated by the development of rice production in Mali over the last few years and the substantial yield increases...
achieved in the Sahel (Mali, Senegal) – demonstrating that irrigated rice is a feasible option in the subregion.

In the Sahel, soil alkalinization followed by sodication may affect soil quality, particularly if groundwater tables rise too close to the surface due to lack of drainage combined with irrigation water rich in dissolved inorganic ions. Soil alkalinization and sodication problems are found in the Office du Niger, Mali, in Foum Gleita, Mauritania, and in irrigated systems in Niger.

Until now, rice-rice or other double-cropping schemes are found only in a few zones (e.g. in the Kou Valley in Burkina Faso or in Niger). There is a clear potential for the introduction of short-duration cultivars that may allow to grow two rice crops per year on the same land, or an additional non-rice crop following rice, profiting from residual moisture in the soil or supplementary irrigation.

**Technical opportunities**

Compared to the upland rice ecosystems, the irrigated rice systems are quite robust and homogeneous in terms of both biophysical and socio-economic characteristics. Innovation and change should concentrate on improving resource-use efficiency and factor productivity.

WARDA and partners have developed improved integrated rice management (IRM) options for irrigated rice cropping in the Sahel that are within farmers’ means, based on farm surveys and farmer participatory on- and off-station research (Wopereis et al., 2001; WARDA-SAED, 2000). IRM focuses on land preparation, crop establishment technique, sowing dates and rates and cultivar choice, and provides a farming calendar for best-bet management for a given site × sowing date × cultivar choice × crop establishment technique combination; relevant information can be adapted to a specific site and to farmers’ means. IRM options further include: fertilizer rates for specific target yields and taking into account farmers’ financial means; weed and water management practices; and harvest and post-harvest techniques.

These IRM options have been evaluated with farmers in Senegal and Mauritania (Hafele et al., 2000), resulting in a mean yield increase of 1.7 tonnes/ha (from 3.8 to 5.5 tonnes/ha). Partial budgeting showed that average net benefit increased from US$215 to US$525 per ha, i.e. an 85 percent increase in net benefits. IRM production costs were slightly higher than farmer production costs, mainly due to basal fertilizer application. Even with this assumption, IRM was economically superior to farmer practices across sites. IRM options most attractive to farmers included improved fertilizer and weed management, use of improved varieties and harvesting and post-harvest technologies. WARDA, NARES (National Agricultural Research and Extension Systems) and NGOs (non-governmental organizations) from Mauritania and Senegal, are now exploring ways to scale up results from these studies to a much larger number of farmers.

Moreover, only a few introduced varieties were grown by farmers in irrigated ecologies of West and Central Africa. WARDA, through inter- and intraspecific crosses, has increased the genetic diversity, and a number of high-yielding, good quality, shorter-duration and salinity-tolerant varieties have been developed and grown by farmers (Table 4).

**Rainfed lowland ecology**

In West and Central Africa alone, an estimated 20 to 40 million ha of inland valley swamps are found, of which only 10 to 25 percent are currently used (Windmeijer, Duivenbooden and Andriesse, 1994). Although WARDA

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**TABLE 4**

New irrigated rice varieties released in West and Central Africa

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Countries</th>
<th>Agronomic characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITA1</td>
<td>Côte d’Ivoire</td>
<td>Blast, iron-toxicity tolerance</td>
</tr>
<tr>
<td>WITA3</td>
<td>Côte d’Ivoire</td>
<td>Blast, iron-toxicity tolerance</td>
</tr>
<tr>
<td>WITA7</td>
<td>Côte d’Ivoire</td>
<td>RYMV resistance</td>
</tr>
<tr>
<td>WITA8</td>
<td>Côte d’Ivoire, Niger</td>
<td>High yield, RYMV resistance</td>
</tr>
<tr>
<td>WITA9</td>
<td>Côte d’Ivoire, Niger</td>
<td>High yield, RYMV resistance</td>
</tr>
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<td>Mashuri</td>
<td>Sierra Leone</td>
<td>High yield</td>
</tr>
<tr>
<td>IR1561-228-3-3</td>
<td>Mali</td>
<td>High yield</td>
</tr>
<tr>
<td>Sahel 108</td>
<td>Mauritania, Senegal</td>
<td>High yield</td>
</tr>
<tr>
<td>Sahel 201</td>
<td>Mauritania, Senegal</td>
<td>High yield</td>
</tr>
<tr>
<td>Sahel 202</td>
<td>Senegal, Mauritania</td>
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</tr>
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</table>
research has shown that no causal linkages exist between water-borne diseases, such as malaria, and the expansion of irrigation in West and Central Africa (WARDA, 1999), farmers still perceive human health problems as a major constraint for the development of lowland areas.

Rainfed lowland systems are more robust than upland systems and have good potential for intensification, but are largely unexploited. Improved water control is definitely a first step towards improving the productivity of the lowlands and controlling iron toxicity. With improved water control, the use of external inputs may become attractive and rice yields may be increased rapidly. As full water control in large schemes is too costly, improvement of water control will have to be limited to smaller schemes.

The rice yields in rainfed lowlands are substantially higher than those in the rainfed uplands, but nevertheless low, averaging 2 tonnes/ha. The potential yield is 3 tonnes/ha at current input levels and 5 to 6 tonnes/ha at increased input levels and with improved water control (i.e. yield levels that are comparable to irrigated systems with full water control in the savannah and humid forest zones). These yield gaps indicate considerable potential for improvement. Poor water control is a major system constraint, prohibiting more intensive use of these systems. Indeed, with improved water control, use of external inputs may become attractive, potentially resulting in higher yields. Although water management is a key factor for intensification, complementary technologies will be needed to provide sufficient opportunities for increased productivity and profitability. Indeed, major biological constraints for rice production in inland valleys, such as iron toxicity, pests and weeds, require major attention to realize those potentials.

**Technical opportunities**

Important spillover effects from technologies developed for irrigated and upland systems are expected. The NERICAs currently available have been developed for upland systems, but are now being screened under lowland conditions. Interspecific progenies of *O. glaberrima* and *O. sativa* subsp. *indica* that were bred for irrigated conditions are also evaluated under lowland rainfed conditions. However, in the near future, water control will not reach the level of the irrigated systems and breeding for lowland conditions will have to take into account multiple stresses such as drought, low N and P conditions and major pests such as RYMV, AfRGM and blast.

In addition to varietal improvement, the sustainable development of rainfed lowlands will require complementary technologies, covering all aspects of lowland rice management, from land preparation to harvest and post-harvest technologies. The basis will be formed by IRM practices developed for irrigated rice systems, but fine-tuning and adaptation according to the site-specific conditions will definitely be required. Besides intensification, the potential for diversification will be explored. Particular emphasis will be given to the integration of vegetables in rice production systems, and possibilities to integrate aquaculture and livestock in inland-valley lowlands.

Sustainable intensification and diversification of lowlands require important investments. Therefore, particular attention will be given to the identification of bottlenecks preventing access to capital and other necessary resources and their adequate management. Market forces drive both diversification and intensification; therefore, a particular focus on peri-urban environments and the efficiency of market linkages is warranted. The capacity of locally produced rice to compete with imported rice should be explored, with respect to the efficiency (cost-effectiveness and rice quality) of small-scale processing units.

Inland valleys have very complex, dynamic and diverse human, social, natural and physical dimensions and interconnections that need to be understood in order to determine options for improved and integrated crop and natural resources management. There is a need to:

- elucidate the different functions of inland valleys and their management;
- unlock constraints to the more widespread use of inland valleys for rice-based systems;
- identify, develop and adapt a wide variety of options and methods for sustainable inland valley development and management; and
- scale up results.

It is clear that with such a high degree of complexity and diversity, research and extension will never arrive at tailor-made recommendations to individually suit the numerous rice growers in the inland valleys. Agricultural research and extension has to provide much more specific information and move beyond simple delivery of general messages, recipes or blanket recommendations to be passed to farmers. Sustainable management of inland valleys requires a fundamental change in innovation,
development and learning processes. Indeed, what is needed are approaches that strengthen farmers’ capacity to make optimal use of the available resources and the best choices of alternative approaches to resource management. This has important implications in terms of intervention methodology and institutions that support change and development, including farmer organizations. Indeed the inherent complexity, diversity and dynamics of inland valley ecosystems call for a bottom-up, social learning process. Only by doing so, can a sustainable and lasting impact on food security be achieved in the region. A participatory learning and action research approach among inland valley development stakeholders (farmers, change agents, extension, research) at grassroots level is required. This will help build bridges between local and indigenous knowledge and scientific expertise. This will ultimately lead to a network of farmer associations in contact with a wide variety of external stakeholders, forming an inland valley platform at regional and national level. It is also important to develop an integrated natural resources management (INRM) framework and curriculum for farmer learning for inland valleys in West Africa.

CONCLUSIONS
Thanks to the development of NERICAs, it has been possible to break the yield barrier in the upland rice ecology. NERICAs are stress resistant, have short growth duration and respond well to both low and high input conditions. Participatory varietal selection (both researcher- and extension-led) and community-based seed supply systems are currently being used to get seeds to farmers. This development will ensure that the contribution of the upland ecology to regional rice production will increase in the years to come. NERICAs are also currently being developed for rainfed and irrigated lowland systems.

Considerable scope for yield improvement also exists in irrigated ecologies. The introduction of integrated rice management (IRM) in irrigated systems in the Sahel has resulted in considerable yield increases (2 tonnes/ha) without major changes in input use, thereby reducing the very large yield gap between actual and potential yields in these systems. IRM is developed with farmers and provides them with options ranging from land preparation to harvest and post-harvest interventions. Existing farmer organizations can often be used as dissemination channels for IRM.

In the long term, the rainfed lowlands also show great promise. Large areas of rainfed lowland have yet to be developed. Considerable scope exists to increase cropping intensity and yields in these systems because of sub-optimal crop management and poor water control. This again calls for an IRM approach. However, these systems are characterized by a much larger complexity and diversity than the irrigated systems. The message that needs conveying is, therefore, also much more complex and will take more time and effort. It is proposed to introduce IRM through a participatory learning and action research (PLAR) approach and the creation of rural knowledge centres. Pilot farmers in rural knowledge centres should ultimately become agents of innovation and change, stimulating the diffusion of knowledge. Research and extension staff should change in the process to assume a much more facilitating role, building bridges between local knowledge and expertise from outside.

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“RICE IS LIFE”: ASPECTS OF RICE-BASED SYSTEMS IN LAC
The slogan of the International Year of Rice (IYR) reflects well the situation in the Latin America and the Caribbean region (LAC). Rice plays a prominent role as a primary food source and rice-based systems are essential for food security, poverty alleviation and improved livelihoods. In the last century, rice became an important staple and a basic cash crop. It evolved from being a dominant pioneer upland crop in the process of expansion of frontier areas in the first half of the century, to becoming, in the past four decades, a well-established, intensive, highly technical crop mainly produced in flooded environments.

Rice production
Rice is now cultivated in 113 countries of the world and on all continents except Antarctica. Of these, 26 countries belong to LAC; they annually produce in excess of 22 million tonnes of paddy. Present world rice production is around 592 million tonnes (2000–02 average), of which LAC represents 4 percent (FAO, 2003). The rice area harvested in LAC is around 5.9 million ha. Annual rates of growth for production over the 1961–1991 period were almost identical in Asia and in LAC (2.9 percent). Most of the growth in Asia was explained by the contribution of enhanced productivity (79 percent). In LAC, yield increase accounted for 51 percent. Over the last decade, rice output in LAC expanded at a rate of 1.9 percent per year (compared to 1.3 percent in Asia), while yields grew at an outstanding rate of 3.8 percent per year (1.0 percent in Asia) and area contracted at a rate of 1.8 percent per year (Table 1). Since 1967, more than 300 new rice varieties have been released in LAC (i.e. about ten new varieties every year), the majority of them (90 percent) targeted to flooded environments. Of the new varieties, 40 percent came from crosses made at CIAT (International Centre for Tropical Agriculture) and several of the others have parentage from CIAT or IRRI (International Rice Research Institute) progenitors. Modern semi-dwarf rice varieties (MSVs) now account for 93 percent of all flooded rice production, itself representing more than 80 percent of total rice production in the region. Average yields in flooded areas have risen from 3.3 tonnes/ha in the mid-1960s to 4.9 tonnes/ha in 2002; and total rice production almost tripled between 1967 and 2002 to reach over 22 million tonnes of paddy rice.

Rice consumption
Throughout the last century, rice gradually became a staple in the diets of consumers in tropical Latin America. Per caput consumption of white rice went from less than 10 kg in the 1920s to approximately 30 kg in the 1990s. Although significant improvements have been witnessed in rice production in LAC, regional demand surpasses production. The region has a net deficit of nearly 1 million tonnes of milled rice per year. Apparent consumption is

<table>
<thead>
<tr>
<th>Year Range</th>
<th>Production</th>
<th>Yield</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961–1991</td>
<td>2.9</td>
<td>2.3</td>
<td>0.6</td>
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<td>2013–2017</td>
<td>1.9</td>
<td>3.8</td>
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<tr>
<td>2018–2022</td>
<td>1.4</td>
<td>1.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

approximately 30 kg/caput for the region’s 511 million inhabitants. There are 14 countries and states in the Caribbean that have little potential for domestic rice production and will continue to be rice importers. However, there are another 14 with a shortfall in local production to meet internal rice needs, but which have the natural resources available to support additional rice production in order to satisfy national demand and even generate surpluses for the export market.

**Nutrition**

In the developing world as a whole, rice provides 27 percent of dietary energy supply and 20 percent of dietary protein intake. Rice is the most important grain crop for human consumption across most of the tropics of LAC. It supplies more calories to these people’s diet than do wheat, maize, cassava or potatoes. In the rapid urbanization process in LAC, where 70 percent of the population now lives in the cities, rice has displaced from the diet traditional, bulky and perishable staples, such as plantains, cassava, yams and potatoes. About half of LAC’s population live below the FAO poverty line, and income is lowest in the tropical parts of the region. Food purchases account for over 50 percent of total expenditures for the poor, and rice accounts for about 15 percent of their total food purchases. With rice prices falling by about 50 percent in real terms over the period, consumers have been the main beneficiaries (Sanint, Córrea-Victoria and Izquierdo, 1998). In the tropical regions of this continent, rice is now well established as a “wage good”. There has been a marked increasing trend in consumption during the last 15 years in high-consuming countries, such as Ecuador, the Dominican Republic, Cuba, Peru, Brazil and Colombia. Rice is the main source of calories and protein for urban dwellers in big centres such as São Paulo, Rio, Porto Alegre, Panama, Barranquilla and Guayaquil. Although the average consumption level is far from that of Asian countries, consumption in Brazil (the largest producer in the region accounting for half of its supply) is 60 kg per caput of paddy rice (equivalent to a daily intake of 400 calories).

**Agrobiodiversity and the environment**

A paramount achievement of rice technologies in LAC was the fact that production tripled while area did not grow. This was largely the result of higher yields in the irrigated sector and it is a vivid example of the release valve effect that higher yields on favourable ecosystems have on other less favourable, more fragile environments. The unit cost of rice fell by over 50 percent in real terms and this was accompanied by a similar fall in prices. Rice ceased to be a preferred crop in less favoured environments and its production moved to the flooded systems. The role of rice in agricultural and rural development has been notorious. The cereal was a key pioneer crop in the early part of the century as traditional and improved tall upland rice varieties were very well adapted to the newly opened, frequently acid soils of the savannahs, the lowlands and the forest margins. Upland rice area peaked at more than 6.0 million ha in 1976, when it accounted for over 75 percent of the rice area in the region. With the incursion of the new semi-dwarf varieties in the 1970s, upland rice lost its competitive ability against the rapidly growing yields and the descending real unit production costs of the flooded rice areas. Currently, upland rice has plunged to below 2.5 million ha (40 percent of the rice cultivated area in LAC), the vast majority of which is still found in the Brazilian Cerrados, as rice production is increasingly concentrated in the more stable lowlands under irrigated and flooded conditions driven by the higher productivity of these systems. Rice-based systems are hubs of biodiversity. They combine well with other agricultural production activities, such as the raising of fish or ducks on waterlogged rice fields, and the feeding of rice straw to livestock. In turn, ducks and fish feed on weeds and small aquatic organisms, while livestock help with transportation and land preparation, as well as providing organic fertilizer. Rice fields also host a wide variety of natural enemies that control harmful insects and pests.

**Water and land management**

In LAC, rice is a key commodity in pasture establishment and renovation, mainly in Brazil (both in the upland Cerrados and in the temperate irrigated areas of the south), Uruguay and Argentina. In the temperate region, the system includes cattle and sheep. While rice was a preferred crop in forest margin settlements in the 1960s and 1970s, the drop in its price associated with higher yields and lower unit costs relegated it (particularly in Central America, Colombia and Ecuador) in the rank of alternatives to maize, cassava, cotton etc. In Brazil, Peru and Bolivia, rice is still important among forest margin settlers. In the Cerrados, besides pastures, rice is a key element in rotation with other crops (mainly soybean). In several flooded areas, rice is the only viable cash crop
and represents a vital tool for the efficient management of such ecosystems. In these ways, rice-based systems provide great opportunities for improved nutrition, diversified agriculture, increased incomes and the protection of genetic and agricultural resources.

**Employment and income**
Rice cultivation is the principal activity and source of income for about 100 million households in Asia and Africa, and several countries are highly dependent on rice as a source of foreign exchange earnings and government revenue. In LAC, there are close to 1 million rice producers. Together with the crop activity, important linkages occur in milling, mechanization and commercialization, as the threshing, milling, processing, market transport and post-harvest of rice help support rural livelihoods and other rural people generate income from producing, servicing and maintaining tools, implements and equipment for rice cultivation and post-harvest operations. Furthermore, rice involves many professional services and has other indirect effects on employment, investment and growth, as well as having an important multiplier effect on aggregate demand; there are places known as “rice regions” and “rice towns”, as this cereal constitutes the life of the community.

**Gender**
Women and men often develop different agricultural expertise and knowledge, and women play important roles in both rice production and post-harvest activities, especially among the traditional farming systems in the forest margins of LAC.

**Science**
Improved technologies enable farmers to grow more rice on limited land with reduced need for water, labour and agrochemicals. In rice cropping, a significant number of scientific developments converge: from biological knowledge and discoveries, to engineering (machinery, irrigation, post-harvest), social sciences, management and statistics. The confluence of all this wealth of information, coupled with resource endowments and attitudes of diverse social groups towards them, configure a very wide array of rice-cropping systems throughout LAC.

**Economic policy issues**
For many decades, rice was one of the most heavily protected agricultural commodities. Since the 1980s, structural adjustment programmes and the 1994 WTO (World Trade Organization) Agreement on Agriculture have changed this situation, and the world rice trade is expanding rapidly; nevertheless, rice remains the most subsidized cash crop in the world. While urban consumers enjoy most of the benefits (especially lower rice prices), many of them face the effects of unemployment associated with the deployment of the national rice production capacity. However, it is rice farmers in developing countries who bear the brunt of the changes. Developing countries now face the challenge of advocating for fair rice trade policies and practices where everyone will be able to reap the benefits associated with more efficient resource allocation.

**CHALLENGES AND OPPORTUNITIES FOR RICE IN LAC**
IYR aims to confront the many issues associated with rice-based systems in a global, coordinated framework in order to positively harness the potential of properly managed rice-based systems. The following discussion touches on the issues identified at global level and puts them in the perspective of LAC.

**Improving nutrition and food security**
Rice must continue its consolidation as a food staple in LAC. It is essential that rice maintains an advantage as a cheap energy source for the poor and that it is produced locally in order to adequately exploit comparative advantages as well as maintain a production base generating employment and income. Several countries have low levels of per capita rice consumption. In those countries with low individual consumption, rice is offered at relatively high prices in presentations of high-quality products (low content of broken grains). Therefore, rice does not compete well with other available carbohydrates, such as wheat, cassava, plantains, potatoes or maize. It is important that the market for rice products be enlarged by tackling the low-income groups with lower quality but much cheaper rice, while at the other end offering products with higher value added (convenience foods, elaborated products etc.). A major challenge for food security in the rural sector is to maintain viable alternatives in the face of huge subsidies in developed nations for major cash crops, such as rice. The effort here must be twofold: increase efficiency and maintain a line that checks unfair trade policies in the world market so as to ensure competitiveness.
Managing water resources in rice ecologies

There is growing concern over the sustainability of global freshwater resources. In Latin America, there are three prevalent approaches for addressing the issue of water scarcity within rice-based systems.

The first two approaches refer to demand and use: one aims to reduce the amount of water required for cultivation; the other focuses on justifying water use by employing each drop of water for multiple uses (an example being the concurrent use of water for irrigation and aquaculture). The third approach focuses on the supply of water and efficient use of water cycles in the atmosphere and environment. LAC possesses abundant water supplies, and the rice producers – as prominent users of the resource – must be vigilantes and promoters of investment in processes of water procurement and supply. IYR can help raise awareness among the many beneficiaries of water in rice fields of the diversity of life forms that are sustained within the rice-based systems while promoting the development of rice cultivation in low-water regimes and the need to foresee water needs and investments in a longer time frame.

Environmental protection

There are a growing number of environmental concerns in rice production. Flooded rice production has been receiving most of the attention in LAC (outside Brazil). Input-use efficiency is necessary to reduce undue pressure on systems; a major challenge is to increase yields without augmenting inputs. Higher precision is required and timing is also a critical issue. IYR provides an opportunity for the exchange among the various stakeholders of concrete ideas on these environmental issues and related challenges and opportunities.

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<td>30</td>
<td>25</td>
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</tbody>
</table>

Source: FAO, 1996.
more than US$400 million. The technology for bridging
the yield gap is already available, but it must be intro-
duced, modified to suit local conditions and, more impor-
tantly, extended to growers. Technology transfer is the
key ingredient to bridging the yield gap, and the focus on
grower associations provides the means for transferring
technology in an economical and sustainable manner.

**Rice in the institutional context**

In the wake of reduced capacity in public agricultural
research and extension, the private sector institutions have
become crucial partners. In 1995, several LAC countries
created the Latin American Fund for Irrigated Rice
(FLAR), a new institutional model financed mainly by
the rice sector and incorporating national and international
public research institutions, as well as the private sector.
This new model is a pioneer of international research.
Currently, nine countries from LAC and CIAT collaborate
to generate new and better technologies for the rice sector
and contribute close to US$600 000 per year. Its main
thrust is on germplasm development, but crop manage-
ment has received increased attention since 2003, when
the Common Fund for Commodities (CFC) granted
(through FAO) almost US$1 million for a 3-year project
to close the yield gap in rice in Venezuela and Brazil.
While FLAR is entering its tenth year of activity, the
challenge to ensure its permanence is still real. Partners
in FLAR are quite diverse in nature, have dissimilar inte-
rests, even conflicting paradigms and opposing commer-
cial interests. But they know the value of international
cooperaion, of research and technological innovation and
of avoiding duplication of efforts. On the other hand,
declining funds for public research are a challenge for
the sustainability of vital partners in that sector, at national
and international level, and the answer must be to pool
resources from all institutions involved and strengthen
strategic alliances within countries and at regional level.

**CONCLUSION**

Latin America tripled its output in the last three decades
due to the rapid adoption of improved varieties while the
area remained basically stagnant at 6 million ha as
production in upland areas was replaced by production
in flooded environments. Consumption steadily grew and
rice became a staple for the urban poor with self-
sufficiency levels above 90 percent. Average yields (3.8
tonnes/ha) are still low as crop management has to close
the gaps to allow varieties to express their yield potential.
The region has abundant supplies of water, land and
people, and represents a potential rice basket for the
world. A major challenge for the region is the
consolidation of FLAR, a pioneer model for rice research
funded mainly by rice sector funds and including
international, national and private research institutions.

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INTRODUCTION – A BRIEF BACKGROUND

The importance of rice

Rice is the staple food for more than half the world’s population. It is the most rapidly growing food source in Africa and is consequential to the food security of an increasing number of low-income food-deficit countries (LIFDCs). In 2002, 575 million tonnes of rice were produced in 113 countries. This figure was, nevertheless, less than that for consumption, with the result that large quantities of rice had to be drawn from the buffer stock to meet demand. Today, there are still about 800 million people suffering from malnourishment and hunger: achieving a sustainable increase in rice production can improve global food security and contribute to poverty alleviation.

Increasing demand

There is growing concern that current levels of rice production will not meet future demand. Production technology from the green revolution has been exhibiting diminishing returns, and the 1990s saw a marked decline in yield growth rate. Since 2000, annual withdrawals from rice stocks have been necessary to bridge the gap between rice production and demand. The world population is projected to increase from 6.13 billion in 2001 to 7.21 billion in 2015 and 8.27 billion in 2030, indicating a corresponding increase in rice demand from 680 million tonnes in 2015 to 771 million tonnes in 2030.

Constraints

The intensive nature of the rice cultivation process can impact the environment. Negative effects include reduced soil fertility, water pollution and the emission of greenhouse gases. The intensive use of a limited number of high-yielding rice varieties over a wide-ranging area and prolonged period of time has reduced genetic diversity. Inefficient use of agrochemicals and pesticides results in pollution and directly harms farmers’ health. In addition, the current demands on land and water for urban and industrial use render the expansion of irrigated rice production unfeasible, especially in Asia, where more than 90 percent of the world’s rice is produced every year.

Water for irrigation is one of the most serious constraints to rice production in the Near East. The reduced storage capacity of reservoirs, increased demand (>50 percent), national policy and the uncertainty of monsoon rainfall and snowfall are all constraints to irrigation and, as a consequence, to rice production. In order to rise to this challenge, it is necessary to use more productive varieties, improve the conservation of natural resources and develop more efficient technologies.

Opportunities for increased production

Opportunities for a sustainable increase in rice production should be exploited. There is a sizeable yield gap between actual and achievable yield in all Near East countries except Egypt, revealing an opportunity to increase the yield of both improved and traditional varieties through efficient production methods. Narrowing the yield gap would also lead to increased income for rice farmers.

Increased efficiency in rice production is possible through varietal technology, advances in yield enhancement, and the successful development of hybrid technology. In Egypt, actual yield (national average) has almost reached potential yield; this achievement is possible throughout the Near East region. Countries with extensive scientific expertise (e.g. the Islamic Republic of Iran and Pakistan) may extend their use of hybrid rice technology to improve rice yield. Similarly, new rice varieties, hybrid rice and the recent development of NERICA (New Rice for Africa) will all help farmers achieve higher yields. It should be stressed that sustainable
improvement in rice production for food security must be achieved with increased efficiency, reduced use of natural resources and minimized environmental impact.

**Facing the challenges**

To overcome hunger, poverty and malnutrition in rice-consuming countries while maintaining productivity and protecting the environment, a coordinated effort is required. Increased awareness – as well as national, regional and global efforts to secure sustainable rice production – is essential. In addition, rice research will play a major role in the efficient utilization of cultivated area, improved rice varieties and the minimization of loss during milling. The major focus of rice research in the next decade must be the development of high-yielding and early-maturing varieties in order to ensure the conservation and efficient use of natural resources.

In order to achieve these goals, the National Rice Research Program in the Near East region should focus its research on the potential for improvement through hybrid rice, technology and biotechnology. Improved utilization of more advanced research techniques would make a significant impact on rice production. For example, in a region where the potential yield is 13 tonnes/ha but national yield averages only 4.73 tonnes/ha, improved production techniques in areas of high salinity would have immense significance.

**THE CURRENT SITUATION IN THE NEAR EAST REGION**

Rice is the most rapidly growing food source in several Near East countries (Egypt, the Islamic Republic of Iran, Iraq, Mauritania, Morocco, Pakistan, Sudan and Turkey). Rice is second to wheat, the region’s most important staple. Rice is the third largest crop in the Near East (after wheat and cotton) in terms of area sown. However, these nations currently account for only a fraction of the global rice area (2.6 percent) and global rice production (2.7 percent). Cultivation area occupies about 3.5 million ha, producing about 2.7 million tonnes of rice, with a regional production average of 4.7 tonnes/ha per year. The region’s rice demand generally exceeds production and – with the exception of Pakistan and Egypt, which have an export surplus of 0.5 and 1.8 million tonnes, respectively – Near East nations are net rice importers. Based on projected population growth and increasing per caput consumption, the increase in production required to meet the demand in a decade is estimated at 30 percent over the present production of 15.7 million tonnes. Achievement of such a high target would require the growth rate of annual production to remain at approximately 3 percent, despite the limited water supply and limited possibilities for the expansion of production area.

Despite the current low production in the Near East, the agro-ecology of the region is quite favourable for high yield. The ecology and climate are ideal for rice agriculture. Nevertheless, production remains stagnant at low levels, with the exception of Egypt. Low yield in many rice-producing countries of this region appears to be caused by poor crop management techniques, lack of research and extension systems, and limited utilization of productive varieties.

High variability between Near East countries exists in rice yield (see Table 1). The average national yield in Egypt is 9.4 tonnes/ha, compared to 1.30 tonnes/ha in Sudan. This type of yield gap is due to differences in: biophysical factors (climate, length of growing season, soil, water, pest pressure etc.); socio-economic factors; crop management; and access to and use of technology. Domestic milled rice production and consumption also vary from one country to another in the Near East region (Table 2). Annual per caput rice consumption ranges from

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**TABLE 1**

Rice area, production and yield in Near East countries, 2002

<table>
<thead>
<tr>
<th>Country</th>
<th>Area ('000 ha)</th>
<th>Production ('000 tonnes)</th>
<th>Average national yield (tonnes/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egypt</td>
<td>600</td>
<td>5 580</td>
<td>9.40</td>
</tr>
<tr>
<td>Morocco</td>
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<td>Islamic Republic of Iran</td>
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<tr>
<td>Mauritania</td>
<td>13</td>
<td>58.81</td>
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</tr>
<tr>
<td>Sudan</td>
<td>5.50</td>
<td>7</td>
<td>1.30</td>
</tr>
<tr>
<td>Total</td>
<td>3 494</td>
<td>12 692.41</td>
<td>4.73</td>
</tr>
</tbody>
</table>
2 kg per person in Morocco (perhaps the lowest in the world) to 43 kg per person in Egypt (one of the highest in the world).

THE TREND OF PRODUCTION, YIELD AND CONSUMPTION IN THE 1990s

In general, the domestic total of milled rice does not meet the demand of consumption. Once again, the exceptions are Pakistan and Egypt; both produce a surplus and export to other countries in this region and throughout the world. Overall, however, domestic rice production is not sufficient for local consumption needs and approximately half of the total consumption in many Near East countries must be imported every year.

The rice production area in the Near East region is dependent on: availability of water for irrigation; rice ecology; production costs; and market prices. These factors have a tremendous effect on total rice production and yield in the region, and indirectly affect imports and exports.

The figures in Table 2 indicate that, overall, the region exports more rice than it imports, but this is, of course, due to the export of rice from Egypt and Pakistan alone. Outside these two countries, rice production does not meet the demand.

Turkey

In Turkey, for example, domestic milled rice production varies between 200 000 and 286 000 tonnes per year and total domestic milled rice consumption is between 450 000 and 536 000 tonnes. The rice production area was more than 70 000 ha in the early 1980s, reaching as high as 77 000 ha in 1982, but then decreasing drastically afterwards. The average rice yield stands at 5 tonnes/ha (Table 3).

Two factors are responsible for the decrease in area allocated for rice:

- Shortage of irrigation water subsequent to the period of drought which prevailed between 1985 and 1994.
- Policy restrictions on rice importation and cultivation. Restrictions were made on rice importation before 1984 through the imposition of taxes on rice imports. These restrictions were lifted or their amounts were reduced in 1984, lowering the cost of rice imports. Production costs were often higher for locally produced rice than for imported rice, and a number of farmers abandoned rice cultivation as a result. Moreover, in some areas, rice cultivation was forbidden during periods of drought, so that the available water could be used for irrigating other crops such as cotton, maize and vegetables. However, rice area started to increase again from 41 000 ha in 1994 to 58 000 ha in 1995, reaching over 60 000 ha in 1996. The increases in 1995 and 1996 were due to increases in rainfall which provided more available water for irrigation.

In the last decade, rice imports increased in Turkey due to the sharp decline in domestic rice production. In 1993, for example, imports reached their highest level (309 000 tonnes) and at times more rice was imported than necessary.

Egypt

In Egypt, the rice-growing area averaged 396 000 ha during 1984–89 and climbed to 563 600 ha in 2002. This was mainly due to expansion in the irrigated area allocated for rice. Total milled rice production increased from 2.4 million tonnes in 1984–89 to 6.04 million tonnes in 2002 (more than meeting the local consumption demand). Rice exports averaged 87 000 tonnes during 1984–89 and reached 500 000 tonnes in 2002.

The fertile soil of the Nile Delta, the high intensity of sunlight, the limited presence of diseases and insect pests, the warm weather and the good irrigation system have all contributed to making Egypt’s yields among the world’s highest at 9.4 tonnes/ha (Table 4) – which is more than three times the world average (3 tonnes/ha).

These high yields were achieved thanks to:

- the release and spread of new short-duration high-yielding varieties (Giza 177, Giza 178, Sakha 101, Sakha 102, Sakha 103, Sakha 104, Giza 182 and Egyptian Yasmine);
- the transfer of appropriate technology to the farming community to improve crop management; and
- the monitoring of production constraints and farmers’ problems in the season, and prompt follow-up action by various agencies under the umbrella of the National Rice Campaign.

Pakistan

In Pakistan, the other major rice-exporting country, rice is the second most important crop in terms of export earnings, contributing about 9 percent per year to foreign exchange earnings. Pakistan exports about 1 million tonnes of rice annually, which is about 10 percent of the
### TABLE 2
Rice consumption in Near East countries, 2001

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (millions)</th>
<th>Total milled rice consumption (’000 tonnes)</th>
<th>Domestic milled rice production (’000 tonnes)</th>
<th>Milled rice imports (’000 tonnes)</th>
<th>Milled rice exports (’000 tonnes)</th>
<th>Per caput rice consumption (kg/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egypt</td>
<td>68</td>
<td>2 924</td>
<td>3 424</td>
<td>-</td>
<td>500</td>
<td>43</td>
</tr>
<tr>
<td>Morocco</td>
<td>25</td>
<td>50</td>
<td>15.6</td>
<td>24</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Turkey</td>
<td>67</td>
<td>536</td>
<td>286</td>
<td>250</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Pakistan</td>
<td>145</td>
<td>1 450</td>
<td>3 250</td>
<td>-</td>
<td>1 800</td>
<td>10</td>
</tr>
<tr>
<td>Iran (Islamic Republic of)</td>
<td>68</td>
<td>2 631</td>
<td>1 831</td>
<td>800</td>
<td>-</td>
<td>38.7</td>
</tr>
<tr>
<td>Mauritania</td>
<td>3.7</td>
<td>148</td>
<td>35.1</td>
<td>91</td>
<td>-</td>
<td>40</td>
</tr>
<tr>
<td>Sudan</td>
<td>35</td>
<td>111</td>
<td>4.5</td>
<td>104</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>411.7</strong></td>
<td><strong>7 739</strong></td>
<td><strong>8 846.2</strong></td>
<td><strong>1 269</strong></td>
<td><strong>2 300</strong></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 3
Rice production and imports in Turkey

<table>
<thead>
<tr>
<th>Year</th>
<th>Production area (’000 ha)</th>
<th>Domestic milled production (’000 tonnes)</th>
<th>Milled rice imports (’000 tonnes)</th>
<th>Total milled consumption (’000 tonnes)</th>
<th>Rough rice yields (tonnes/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>73</td>
<td>198</td>
<td>26</td>
<td>224</td>
<td>4.52</td>
</tr>
<tr>
<td>1982</td>
<td>77</td>
<td>210</td>
<td>21</td>
<td>231</td>
<td>4.55</td>
</tr>
<tr>
<td>1983</td>
<td>70</td>
<td>189</td>
<td>10</td>
<td>199</td>
<td>4.50</td>
</tr>
<tr>
<td>1984</td>
<td>64</td>
<td>168</td>
<td>85</td>
<td>253</td>
<td>4.38</td>
</tr>
<tr>
<td>1985</td>
<td>60</td>
<td>162</td>
<td>85</td>
<td>247</td>
<td>4.55</td>
</tr>
<tr>
<td>1986</td>
<td>55</td>
<td>165</td>
<td>86</td>
<td>251</td>
<td>5.00</td>
</tr>
<tr>
<td>1987</td>
<td>53</td>
<td>165</td>
<td>159</td>
<td>324</td>
<td>5.19</td>
</tr>
<tr>
<td>1988</td>
<td>51</td>
<td>158</td>
<td>91</td>
<td>249</td>
<td>5.16</td>
</tr>
<tr>
<td>1989</td>
<td>66</td>
<td>198</td>
<td>221</td>
<td>419</td>
<td>5.00</td>
</tr>
<tr>
<td>1990</td>
<td>46</td>
<td>138</td>
<td>191</td>
<td>329</td>
<td>5.00</td>
</tr>
<tr>
<td>1991</td>
<td>40</td>
<td>120</td>
<td>133</td>
<td>253</td>
<td>5.00</td>
</tr>
<tr>
<td>1992</td>
<td>43</td>
<td>129</td>
<td>265</td>
<td>394</td>
<td>5.00</td>
</tr>
<tr>
<td>1993</td>
<td>45</td>
<td>135</td>
<td>309</td>
<td>444</td>
<td>5.00</td>
</tr>
<tr>
<td>1994</td>
<td>41</td>
<td>120</td>
<td>200</td>
<td>320</td>
<td>4.49</td>
</tr>
<tr>
<td>1995</td>
<td>58</td>
<td>176</td>
<td>n.a.</td>
<td>n.a.</td>
<td>5.10</td>
</tr>
</tbody>
</table>

### TABLE 4
Trends of area, production and yield increase in Egypt, 1985–2002

<table>
<thead>
<tr>
<th>Year</th>
<th>Area planted (’000 ha)</th>
<th>Production (million tonnes)</th>
<th>Yield (tonnes/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>396</td>
<td>2.4</td>
<td>5.7</td>
</tr>
<tr>
<td>1990</td>
<td>435</td>
<td>3.17</td>
<td>7.3</td>
</tr>
<tr>
<td>2000</td>
<td>563</td>
<td>6.00</td>
<td>9.1</td>
</tr>
<tr>
<td>2002</td>
<td>647</td>
<td>6.04</td>
<td>9.4</td>
</tr>
<tr>
<td><strong>Growth 1985-2002</strong></td>
<td><strong>63%</strong></td>
<td><strong>158%</strong></td>
<td><strong>64%</strong></td>
</tr>
</tbody>
</table>

### TABLE 5
Rice production and export in Pakistan

<table>
<thead>
<tr>
<th>Year</th>
<th>Production (tonnes)</th>
<th>Harvested area (ha)</th>
<th>Yield (kg/ha)</th>
<th>Import (tonnes)</th>
<th>Export (tonnes)</th>
<th>Consumption (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>4 684 800</td>
<td>1 933 100</td>
<td>2 423</td>
<td>3</td>
<td>1 086 641</td>
<td>32</td>
</tr>
<tr>
<td>1985</td>
<td>4 378 400</td>
<td>1 863 200</td>
<td>2 349</td>
<td>7</td>
<td>718 686</td>
<td>-</td>
</tr>
<tr>
<td>1990</td>
<td>4 891 200</td>
<td>2 112 700</td>
<td>2 315</td>
<td>25</td>
<td>743 889</td>
<td>28.8</td>
</tr>
<tr>
<td>1995</td>
<td>5 920 000</td>
<td>2 161 800</td>
<td>2 738</td>
<td>68</td>
<td>1 852 267</td>
<td>20.5</td>
</tr>
<tr>
<td>1997</td>
<td>6 546 450</td>
<td>2 232 000</td>
<td>2 880</td>
<td>-</td>
<td>-</td>
<td>10.0</td>
</tr>
</tbody>
</table>
world rice trade. Annual exports (about 250 000 tonnes) of long-grained, aromatic, fine-quality rice (Basmati) go mainly to the Near East market. About 500 000 tonnes of long-grain rice are exported each year to South and Southeast Asia. The international market price for Basmati rice has been three times that of the modern varieties. In 1995, Pakistan exported 1.6 million tonnes of rice in response to strong demand in the world market.

Despite the fairly stable irrigation and water supply, rice yields remain low for both traditional Basmati and modern varieties. The national average yield is 1.9 tonnes/ha. There is potential for about 25 percent higher yield at the present input level, and this could be achieved by advanced rice crop management. Stagnating or declining yields are thought to be due to:

- the increasing incidence of salinity resulting from injudicious use of irrigation water;
- mismanagement of fertilizer use;
- unfit groundwater;
- soil nutrient depletion;
- the development of insect pest and weed complexes peculiar to the rice-wheat system; and
- inadequate economic incentives for long-term investments in land and soil improvements.

### CONSTRAINTS IN THE NEAR EAST AND NORTH AFRICA

#### General constraints affecting rice production in the Near East region

##### Climatic

- **Low temperatures**: Low temperature is a major constraint to rice production, especially for late-sowing rice varieties.

- **High temperatures**: At a certain stage of development, strong heat may cause a high percentage of sterility, potentially reaching 100 percent at temperatures of 39°C in the dry season.

- **Hygrometry of air, dry and hot winds**: Low air hygrometry and dry hot winds in the dry season affect flowering. Hot winds dry up panicles and can cause the sterility of spikelets.

- **Rain**: Rain can be a constraint during the grain maturation stage, affecting the moisture of the rice grain. This can significantly affect the final rice yield.

#### Soil and water

- **Salinity of soils**: Soil salinity constitutes a significant constraint to rice in many countries of the Near East region. The use of improper irrigation without drainage could encourage waterlogging, resulting in salinity build-up and other mineral toxicities.

- **Irrigation water**: Limited water supply in the region is a major constraint to rice production, which relies heavily on irrigation water. In addition, irrigation water can cause soil degradation due to high levels of sodium bicarbonates. These can lead to a long-term phenomenon of iodination, which may facilitate the rise of pH levels and result in the destruction of the superficial layer of soil and organic matter.

#### Biological constraints

- **Weeds**: Weeds reduce rice yield by competing for space, nutrients, light and water and by serving as hosts for pests and diseases. Under typical conditions, weed growth control is often not properly handled. The spread of weeds is often caused by inadequate land-levelling, improper irrigation methods and inappropriate agricultural techniques, including: seeds mixed with weeds, insufficient soil tilling, inappropriate sowing methods and lack of crop rotation. Various weed control methods, such as complementary practices, hand weeding, mechanical weeding, chemical weeding and integrated approaches, are necessary to improve weed control.

- **Birds**: In the dry season, many farmers avoid cultivation because of the damage birds cause to the rice crop.

- **Field mice**: In some places, field mice can completely devastate farms.

### TABLE 6

**Exports of rice (Basmati and other varieties)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Basmati</th>
<th>Other varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994–95</td>
<td>452 300</td>
<td>1 399 967</td>
</tr>
<tr>
<td>1995–96</td>
<td>716 392</td>
<td>884 132</td>
</tr>
<tr>
<td>1996–97</td>
<td>457 245</td>
<td>1 309 961</td>
</tr>
<tr>
<td>1997–98</td>
<td>552 377</td>
<td>1 538 866</td>
</tr>
<tr>
<td>1998–99</td>
<td>588 763</td>
<td>1 200 011</td>
</tr>
<tr>
<td>1999–00</td>
<td>569 823</td>
<td>1 346 231</td>
</tr>
<tr>
<td>2000–01</td>
<td>502 061</td>
<td>1 792 224</td>
</tr>
<tr>
<td>2001–02</td>
<td>543 750</td>
<td>1 100 868</td>
</tr>
<tr>
<td>2002–03 (July–May)(^a)</td>
<td>645 781</td>
<td>1 000 829</td>
</tr>
</tbody>
</table>

\(^a\) Estimates.

*Source: Federal Bureau of Statistics, Pakistan.*
• **Disease**: Rice can serve as a host to many diseases and pests, including: bacterial blight, bacterial leaf streak and bacterial sheath rot. Many viruses have also been identified.

**Socio-economic factors**

• **Supply of goods**: Fertilizer is very expensive and not always available. There is an insufficient quantity of certified seeds; this has led some producers to buy bad quality seeds.

• **Agricultural equipment**: Lack of agricultural equipment or outdated hydraulic equipment can be a major constraint to rice production. Manual transplantation of the plant population results in fewer plants per hectare. The optimum plant population (approx. 220,000 per ha) is difficult to maintain, and manual transplantation typically results in about 120,000 per ha.

• **Rehabilitation of agricultural perimeters**: Perimeters are poorly constructed and do not last long because of the absence of construction norms.

• **Agricultural credit**: UNCACEM (Mauritanian National Credit and Savings Union of Agricultural Cooperatives) agricultural credit faces many problems, such as:
  - late credit grants;
  - poor capacity for financing agricultural campaigns;
  - heavieness of procedures in obtaining loans;
  - difficulties related to credit recovery; and
  - weak credit capacity to purchase agricultural equipment.

**POST-HARVEST TECHNOLOGY AND LOSS IN THE NEAR EAST REGION**

Harvesting is done manually throughout most of the Near East region. Due to variations in post-harvest techniques and the methodology of harvesting, threshing, storage and milling, varying levels of loss occur in each country.

Between 10 and 37 percent of the product can be lost in post-harvest operations. Current statistics reveal the following breakdown:

• shattering through harvesting (1–3%)
• handling (2–7%)
• threshing (2–6%)
• storage (2–6%)
• transportation (2–10%)
• drying (1–5%)

Throughout rice-producing areas, rough rice is generally dried for some time after harvesting and then stored in sacks. The moisture content of rough rice must be below 14 percent before it can be safely stored. However, rice is normally harvested with a moisture content of 23 percent or more. If the moisture content is not reduced to below 14 percent for storage, grain quality deteriorates through microbial activity and damage from pests.

Farmers dry combine-harvested rice with mechanical dryers. However, mistakes can occur during the drying process: for example, not drying the crop within the appropriate time may result in damage to the crop due to fermentation (high moisture content), while drying the crop at higher-than-recommended temperatures may result in increased breakage of the milled rice.

While mechanical drying between 12 and 24 hours after harvest is recommended, many farmers are still dependent on air-drying. Two sun-drying methods are generally used. The first method is to place harvested rice in loose bundles and leave it to dry in the field for several days. The length of drying time will depend on weather conditions. This traditional method is not commonly used today. The second method is to spread the wet grains on a drying surface immediately after harvesting. Repeated stirring when using this method is necessary in order to obtain uniform drying. Farmers sometimes keep the crop in the sun longer than is required, and the rice crop will then contain more moisture than is recommended; if the stirring is not repeated frequently, this may lead to heterogeneous drying. Any of these problems will result in the decrease of head rice yield and grain quality.

**ACHIEVEMENTS IN RESEARCH AND TECHNOLOGY TRANSFER IN SELECTED COUNTRIES OF THE NEAR EAST REGION**

**Egypt**

Despite limited land and water resources, increases in yield and productivity have been achieved through a well-organized interdisciplinary team. There has been a significant reduction in the gap between yield potential and the national average. Egypt is now one of the few countries in the world with an average yield of 9.4 tonnes/ha, and demonstration field trails show potential for even higher yields of 13 tonnes/ha (Table 7).

The yield gap reduction was achieved by encouraging farmers (through extension services and national campaigns) to adopt improved production techniques.
In an effort to strengthen rice research in Egypt, a Rice Research and Training Center (RRTC) was established in 1987 in Sakha, Kafr El-Sheikh Governorate with the strong support of three important agencies:

- Egyptian Ministry of Agriculture and Land Reclamation.
- IRRI (International Rice Research Institute), which provided technical support.
- USAID (United States Agency for International Development), which funded the Rice Research and Training Project (June 1980 to December 1986), the National Agricultural Research Project (NARP) supervised by IRRI and, recently, the Agricultural Technology Utilization and Transfer (ATUT) Project.

The RRTC in Sakha, Kafr El-Sheikh Governorate has a full range of well-equipped research facilities, including laboratories, greenhouses, screen houses, libraries, seed-testing centres, cleaning and storage facilities and mechanical workshops. It has 90 research workers, 25 senior staff members, 35 research assistants and some 50 research technicians. The RRTC also has three testing stations in Gemmiza, Zarzoura and Sirw, and 20 on-farm verification sites in the seven rice-growing governorates (Kafr El-Sheikh, Dakahlia, Beheira, Sharkia, Gharbia, Damietta and Fayoum). The National Rice Research Program employs about 200 rice production advisors scattered across the seven rice-growing governorates to help disseminate the improved technology from the Sakha research facilities to the various districts in Egypt.

**Egyptian research programme activities**

- Plant breeding, to develop new improved varieties with resistance to diseases and pests, early maturity and short stature.
- Seed production, to put the seeds of the new high-yielding varieties into farmers’ hands.
- Agronomy, including plant nutrition, water management and cultural practices, to maximize the yield of the newly released varieties.
- Plant protection against weeds, diseases, insects and other pests.
- Mechanization, seeking small-scale implements that can be locally manufactured and maintained.
- Economics, keeping in mind that successful new technology usually cuts costs.
- Extension, to verify and transfer new technology to the farmers.

**Morocco**

Research is currently undertaken within the National Institute for Agricultural Research in Morocco (INRA-Maroc). Research is directed towards conservation agriculture. In this respect, different irrigation methods have been tested to take the place of flooding methods. Thus, physiological parameters under Moroccan conditions have been studied in water-deficient environments. With regard to rice-breeding programmes, Morocco depends mainly on imports of rice materials of Italian, French and Egyptian origin. Efforts are being made to release local varieties.

**Turkey**

The average rice yield 20 years ago was around 4 tonnes/ha. Recently, as a result of the development of new varieties and the adoption of new technologies, the average rice yield has increased to 6 tonnes/ha. However, there is still a large gap between farmers’ yields and experimental results: a gap of between 2.5 and 3.0 tonnes/ha. In addition to breeding activities, research in Turkey covers the following areas:

- rice planting and harvesting time;
- the appropriate fertilizer rate and nitrogen form;
- nitrogen application time;
- seed rate per unit area; and
- irrigation studies:
  - sprinkler irrigation; and
  - minimum water requirements.

An effective certified seed programme has been developed. Certified seeds of commercial varieties are produced every year. The use of these certified seeds has increased both yield and milled rice quality.
Pakistan
Efforts are being made to focus on demand-oriented cultivars and research techniques. For example, the Government is now focusing on the increase in area for fine varieties and the introduction of hybrid rice in areas where coarse varieties are grown. At the same time, knowledge of improved agronomic practices is also disseminated through different sources and electronic media.

Islamic Republic of Iran
The Rice Research Institute of Iran (RRII) was officially established in 1993 to coordinate research activities and projects throughout the country. RRII helps Iranian farmers grow more rice on limited land with less water and fewer inputs. The institute conducts research in 16 rice-growing provinces and has two main centres: in Rasht (RRII headquarters) and in Amol.

RRII has a total of 250 staff members. The institute puts great emphasis on its relations with IRRI in the Philippines. Thanks to this collaboration, the institute has been able to train numerous staff members with short-term and degree courses. The institute also collaborates with IRRI in the International Network for Genetic Evaluation of Rice (INGER). Research activities at RRII are currently conducted in four departments:
- Agronomy and Plant Breeding
- Plant Protection
- Soil and Water
- Agricultural Engineering

The Agronomy and Plant Breeding department works on inbred and hybrid rice varieties using conventional breeding, mutation breeding, tissue culture and biotechnology techniques. The principal objectives are to improve grain quality, yield potential, resistance to pests, disease, drought and lodging, as well as to develop early-maturing varieties.

The Plant Protection department focuses its activities on reducing pesticide use, introducing environmentally friendly pesticides, using alternatives to chemicals, mass production using an artificial diet and finding sources of resistance in rice germplasm to major pests and diseases.

The primary objectives of the Soil and Water department are to: optimize chemical fertilizer input in different soil types; determine the nutrition and water requirements for different varieties; and select low-input varieties.

The Agricultural Engineering department undertakes diverse projects in the areas of food science and technology, machinery and irrigation. These projects seek to optimize the use of machinery, increase water efficiency, decrease yield loss from production to post-production stages and utilize waste from rice production.

The institute also has a technical services department, which provides support to all projects and strengthens the institute’s scientific capabilities. In recent years, the institute has introduced more than ten modern high-yielding varieties, including Fajr, Nemat, Neda, Sazandegi, Churam 1, Churam 2 and Azar. In addition, ten new promising lines are in the final stages of release in the provinces of Guilan, Mazandaran, Khuzestan and Fars.

Mauritania
Agricultural research on rice started in 1972 with IRAT (Institute for Research in Tropical Agriculture and Food Crops).

In 1974, OMVS (Senegal River Development Organization) from UNDP-FAO at CNRADA (National Centre for Agricultural Research and Development) was created to cover irrigated crops, in particular rice. In 1975, a department of rice research was instituted to lead all activities of rice research. Since then, research has greatly evolved, with steady increases in the number of research activities.

The work done in irrigated rice research has dealt mostly with varietal development and agricultural techniques. The results of research activities have made it possible to mark the performance of existing varieties (e.g. short- and medium-duration varieties). The most recently released varieties are all short-duration (eight varieties) with yields ranging from 6 to 8 tonnes/ha.

GERMPLASM AVAILABILITY AND VARIETAL DEVELOPMENT IN SELECTED COUNTRIES OF THE NEAR EAST AND NORTH AFRICA REGION
Research programmes on varietal development are a consistent focus of many research institutions in the Near East and North Africa region. Research institutes are focusing more on market-oriented germplasm. Four types of germplasm are commonly grown: indica, Basmati and Jasminium. In the Near East region, the most common is the short-grain japonica type. Aromatic Basmati varieties, however, are found in Pakistan and the Islamic Republic of Iran.
Egypt
Significant improvements to rice yield in Egypt have been achieved through the development of new improved varieties with high yield potential, early maturation and high resistance to blast disease. These varieties are widely accepted by farmers and consumers, and their high yields were achieved through:
- the release and spread of new short-duration high-yielding varieties (Giza 177, Giza 178, Sakha 101, Sakha 102, Sakha 103, Sakha 104, Giza 182 and Egyptian Yasmine);
- the transfer of appropriate technology to the farming community to improve crop management; and
- the monitoring of production constraints and farmers’ problems throughout the season, and prompt follow-up action by various agencies under the umbrella of the National Rice Campaign.

Morocco
Table 9 lists the varieties inscribed in the official national catalogue.

**TABLE 8**
Yield and ancillary traits of the new released rice varieties in Egypt

<table>
<thead>
<tr>
<th>Variety</th>
<th>Yield (tonnes/ha)</th>
<th>Duration (days)</th>
<th>Height (cm)</th>
<th>Blast</th>
<th>Grain type&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Milling (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Improved varieties:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giza 177</td>
<td>10.7</td>
<td>125</td>
<td>100</td>
<td>3</td>
<td>R</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Giza 178</td>
<td>12.1</td>
<td>135</td>
<td>100</td>
<td>2</td>
<td>R</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Sakha 101</td>
<td>11.5</td>
<td>140</td>
<td>90</td>
<td>2</td>
<td>R</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Sakha 102</td>
<td>10.8</td>
<td>125</td>
<td>105</td>
<td>2</td>
<td>R</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Sakha 103</td>
<td>10.9</td>
<td>120</td>
<td>99</td>
<td>2</td>
<td>R</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Sakha 104</td>
<td>11.4</td>
<td>132</td>
<td>105</td>
<td>2</td>
<td>R</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Giza 182</td>
<td>11.7</td>
<td>129</td>
<td>94</td>
<td>2</td>
<td>R</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td>Egyptian Yasmine&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.5</td>
<td>150</td>
<td>95</td>
<td>1</td>
<td>R</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>11.1</td>
<td>135</td>
<td>98.5</td>
<td>1–3</td>
<td>R</td>
<td>Sh–L</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variety</th>
<th>Yield (tonnes/ha)</th>
<th>Duration (days)</th>
<th>Height (cm)</th>
<th>Blast</th>
<th>Grain type&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Milling (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Old varieties:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giza 171</td>
<td>7.3</td>
<td>160</td>
<td>140</td>
<td>7</td>
<td>S</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Giza 176</td>
<td>8.7</td>
<td>150</td>
<td>100</td>
<td>5</td>
<td>S</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Giza 181</td>
<td>9.1</td>
<td>150</td>
<td>95</td>
<td>2</td>
<td>R</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>8.4</td>
<td>153</td>
<td>112</td>
<td>2–7</td>
<td>R–S</td>
<td>Sh–L</td>
</tr>
</tbody>
</table>

<sup>a</sup>Aromatic rice.
<sup>b</sup>R = resistant; S = susceptible.
<sup>c</sup>Sh = short; L = long.

**TABLE 9**
Varieties inscribed in the national catalogue in Morocco

<table>
<thead>
<tr>
<th>Variety</th>
<th>Yield (tonnes/ha)</th>
<th>Duration (days)</th>
<th>Lodging&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Blast&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Grain type&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triomphe</td>
<td>6.6</td>
<td>143</td>
<td>R</td>
<td>S</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>446</td>
<td>6.2</td>
<td>118</td>
<td>PR</td>
<td>S</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td>Dinar</td>
<td>6.5</td>
<td>139</td>
<td>PR</td>
<td>PS</td>
<td>Jap. (M)</td>
</tr>
<tr>
<td>Hayat</td>
<td>6.8</td>
<td>129</td>
<td>R</td>
<td>PS</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Kanz</td>
<td>6.6</td>
<td>129</td>
<td>R</td>
<td>PS</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Samar</td>
<td>7.0</td>
<td>135</td>
<td>R</td>
<td>PS</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Maghreb</td>
<td>7.1</td>
<td>118</td>
<td>R</td>
<td>T</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td>Bahja</td>
<td>7.13</td>
<td>118</td>
<td>R</td>
<td>T</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td>Nachat</td>
<td>7.29</td>
<td>118</td>
<td>R</td>
<td>T</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td>Farah</td>
<td>10.0</td>
<td>135</td>
<td>R</td>
<td>R</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td>Oumnia</td>
<td>9.0</td>
<td>130</td>
<td>R</td>
<td>T</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td>Gharbia</td>
<td>9.5</td>
<td>130</td>
<td>R</td>
<td>T</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td>Zena</td>
<td>7.9</td>
<td>114</td>
<td>R</td>
<td>T</td>
<td>Ind. (L)</td>
</tr>
<tr>
<td>Riva</td>
<td>8.0</td>
<td>116</td>
<td>R</td>
<td>T</td>
<td>Ind. (L)</td>
</tr>
</tbody>
</table>

<sup>a</sup>R= resistant; PR= less resistant; S= susceptible; PS =less susceptible; T= tolerant.
<sup>b</sup>Sh = short; M = medium; L = long.
Turkey

Many japonica-type rice germplasm varieties have been introduced from Italy, Bulgaria, Spain, France, Hungary and Russia. There are also 500 to 600 lines currently being developed for a crossing programme. The national gene bank of Turkey stores local materials and materials introduced from the European rice-growing community.

Pakistan

Four types of germplasm are commonly grown. The fine types include Basmati super, Basmati 385 and Basmati 2000, while the coarse types include the common variety irri-6. Varietal development is ongoing and research institutions focus increasingly on market-oriented germplasm. Efforts in the public and private sector, with the collaboration of Chinese scientists, are under way to introduce hybrid rice. However, there are several funding constraints. A collaborative approach could help to speed up the ongoing work in the research sector.

Islamic Republic of Iran

The most popularly grown local varieties are Hassan Sarai, Domsiah, Binam, Hassani, Salari, Anbarbo and Sang Tarom (Table 11). Despite the low yield of these local varieties (average 2.5–3.5 tonnes/ha), they have excellent quality traits (aroma and moderate amylose content) popular with consumers. More than 70 percent of the total rice area in the Islamic Republic of Iran still cultivates these varieties. Similar to Basmati types, they are characterized by tall stature (125–135 cm), sensitivity to lodging, long slender grain, 60 to 63 percent head rice recovery (HRR), intermediate amylose content (AC), aroma and elongation qualities, and can be be susceptible to blast and stem borer.

Mauritania

Through collaboration with international research institutions, including WARDA (The Africa Rice Center), researchers have successfully developed new high-yielding varieties adapted to the agro-ecological conditions of the country.

About 1 500 to 2 000 tonnes of certified seeds are required per year. Seed production, however, is between 900 and 1 300 tonnes. The deficit is covered each year by importation from Senegal: 200 tonnes in 1998, 400 tonnes in 1999 and 800 tonnes in 2000.

### Table 10

<table>
<thead>
<tr>
<th>Variety</th>
<th>Grain yield potential (tonnes/ha)</th>
<th>Duration (days)</th>
<th>Plant height (cm)</th>
<th>Grain type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trakya</td>
<td>8.5</td>
<td>128</td>
<td>113</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Ergene</td>
<td>7.0</td>
<td>117</td>
<td>100</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Meriç</td>
<td>8.2</td>
<td>125</td>
<td>110</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>psala</td>
<td>8.2</td>
<td>125</td>
<td>110</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Ayroyaz1</td>
<td>7.5</td>
<td>127</td>
<td>112</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Sürek-95</td>
<td>8–10</td>
<td>130</td>
<td>100</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Osmanck-97</td>
<td>8–10</td>
<td>130</td>
<td>95</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Kral</td>
<td>9–10</td>
<td>125</td>
<td>90</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Demir</td>
<td>10–12</td>
<td>135</td>
<td>85</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Yavuz</td>
<td>8–9</td>
<td>130</td>
<td>100</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Nei</td>
<td>7–8</td>
<td>126</td>
<td>106</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Gönen</td>
<td>7–8</td>
<td>126</td>
<td>108</td>
<td>Jap. (Sh)</td>
</tr>
<tr>
<td>Karg1</td>
<td>8.0</td>
<td>125</td>
<td>110</td>
<td>Jap. (Sh)</td>
</tr>
</tbody>
</table>

### Table 11

<table>
<thead>
<tr>
<th>Variety</th>
<th>Yield (tonnes/ha)</th>
<th>Growth duration (days)</th>
<th>Plant height (cm)</th>
<th>Amylose content</th>
<th>Grain length</th>
<th>Grain type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hassan Sarai</td>
<td>3.5–4</td>
<td>120–125</td>
<td>135</td>
<td>20</td>
<td>Very long</td>
<td>Indica</td>
</tr>
<tr>
<td>Domsiah</td>
<td>3.5–4</td>
<td>130–135</td>
<td>130</td>
<td>20</td>
<td>Very long</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Binam</td>
<td>3.5–4</td>
<td>120–125</td>
<td>135</td>
<td>21</td>
<td>Medium</td>
<td>Aromatic</td>
</tr>
<tr>
<td>Hassani</td>
<td>3–3.5</td>
<td>105–110</td>
<td>115</td>
<td>22</td>
<td>Short</td>
<td>Japonica</td>
</tr>
<tr>
<td>Salarie</td>
<td>3–3.5</td>
<td>125–130</td>
<td>140</td>
<td>23</td>
<td>Very long</td>
<td>Indica</td>
</tr>
<tr>
<td>Anbarbo</td>
<td>2.5–3</td>
<td>120–125</td>
<td>130</td>
<td>19</td>
<td>Medium</td>
<td>Japonica</td>
</tr>
<tr>
<td>Sang Tarom</td>
<td>3–3.5</td>
<td>115–120</td>
<td>125</td>
<td>20</td>
<td>Long</td>
<td>Aromatic</td>
</tr>
</tbody>
</table>
The following varieties are performing well in Mauritania:
- Short-day varieties: SAHEL 108, IR 1561 and IR 64 (the potential yield of these varieties can reach 10 tonnes/ha in research stations).
- Long-day varieties: Sahel 202 and Sahel 201 (the potential yield of these varieties can be as high as 11 tonnes/ha).

RESEARCH PROGRAMMES
The development of interdisciplinary research programmes for improved production will succeed in narrowing the yield gap and will encourage more farmers to adopt improved production techniques. A successful programme must focus on the following disciplines:
- Plant breeding – to develop improved varieties with resistance to disease and pests, early maturity and short stature.
- Seed production – to ensure that pure seeds of new high-yielding varieties are put into the farmers’ hands.
- Agronomy – including plant nutrition, water management and cultural practices to maximize yields of newly released varieties.
- Plant protection – against weeds, disease, insects and other pests.
- Mechanization – seeking small-scale implements which can be locally manufactured and maintained.
- Economics – cutting costs with successful advancement in technology.
- Extension – to verify and transfer new technology to farmers.
- Release and spread of new short-duration high-yielding varieties resistant to disease and pests.
- Transfer of appropriate technology to the farming community.
- Monitoring production constraints throughout the season and following up promptly with appropriate action by various agencies under the umbrella of the National Rice Campaign.

INTEGRATED CROP MANAGEMENT IN THE NEAR EAST AND NORTH AFRICA REGION
Yield stagnation in different regions has led to the development of innovative practices for sustainably maximizing the productivity of rice-based systems. Typically, however, the use of such practices will focus on only one area, such as enhancing productivity, profitability or environmental safety. But what is actually achievable through an integrated crop management (ICM) system would cover the entire production system. This has been the basis for designing and experimenting with various forms of integrated crop management.

Integrated crop management may be defined as: “a site specific crop production strategy, harnessing the synergistic benefits of improved/innovative practices towards sustainable productivity”. With the direct involvement of farmers on a location-specific basis, this strategy is an effective way of conserving resources, maximizing efficiency and directly transferring technology to the farming community.

The System of Rice Intensification (SRI) is probably the earliest form of ICM developed. SRI stresses transplantation of very young seedlings at one per hill, adopting wide spacing, frequent weeding and stirring of soil in the early stages and intermittent irrigation. In 1986, the New South Wales Department of Agriculture (Australia) developed a package called “RiceCheck”, based on the practices adopted in high-yield farms. The system, with provisions for collaborative learning, encourages farmers themselves to monitor and evaluate crop performance against the level of adoption of the checks. The system – which stresses field layout, timely sowing/transplanting, uniform establishment, application of adequate fertilizer nutrients to ensure between 500 and 1 000 tillers at PI (panicle initiation) stage and top-dressing based on the NIR (nitrogen-infra-red) tissue test, N-application before flooding, achieving minimum water depth during early microspore stage and effective post-harvest handling – has been reported to increase yield by 10 percent. Still more refined ICM practices have been developed quite recently in the farms of Indonesia. These practices involve a more systematic and comprehensive approach from seed to harvesting. More recently, a refined ICM package integrating some of the earlier proven skills and practices has been developed and evaluated extensively in research farms and farmers’ fields in Indonesia. The system involving all the stakeholders is more comprehensive in its content and systematic in the implementation process. The system comprises core options and location-specific options. Core options are:
- use of quality seed at a low seed rate;
- transplanting of seedlings at about 15 days old; and
- adoption of LCC- (leaf-colour chart) and NOP- (nutrient omission plot) based N and K or P application.
Location-specific options include:
- planting one or two seedlings per hill;
- square or paired row planting adopting wide spacing;
- intermittent (dry-wet) irrigation management;
- harvesting at right grain moisture; and
- proper drying and storage.

Evaluation of a large number of farmer-managed ICM sites revealed a yield advantage of over 1 tonne/ha and overall profits in excess of US$100/ha per season over non-ICM farms. Accelerated research during the last 10 years at IRRI and NARES (National Agricultural Research and Extension Systems) in tropical Asia has led to the development of many efficient alternative technologies in tillage, crop establishment, water and nutrient management, pest-weed management and post-harvest handling.

Recognizing the advantage of ICM packages will prompt the extensive adoption of ICM practices and could have a wide impact in the Near East and North Africa region. Integrated crop management systems involving varieties or hybrids with new yield thresholds will prove a valuable strategy for maximizing productivity on a sustainable basis.

FUTURE PROSPECTS

The average rice yield in the Near East region is about 4.73 tonnes/ha, which is higher than the world average of 3.3 tonnes/ha. The total land area under paddy rice cultivation in the world is 147 million ha. Comparatively, the average is much lower in the Near East region than in other temperate regions (e.g. Australia, California, Spain and Greece). According to FAO statistics, Near East countries currently produce only a limited amount of rice globally (estimated at around 13 million tonnes). This is only about 2.2 percent of total world production (575 million tonnes).

Countries in the region reveal big differences in productivity: the highest level of productivity is in Egypt (9.4 tonnes/ha), the lowest in Sudan (1.3 tonnes/ha).

The potential for improved productivity in the region, however, is high, making development in rice production all the more important. The conditions for rice cultivation are the same as those in countries which record high productivity.

Productivity can be increased with the introduction of improved rice varieties and new growing techniques. Recently, new high-yielding varieties have been developed in the region showing potential of up to 10 tonnes/ha.

Increasing cultivation area – although dependent on irrigation water – will make it possible to increase productivity as well. Therefore, efforts must be made to focus on demand-oriented cultivars and research techniques.

Governments in the region are focusing on an increase in area for the production of fine type rice, and on an introduction of hybrid rice in countries such as Pakistan and Egypt. Further development of policies at national level will continue to be necessary for sustainable rice production.

STRATEGIES FOR SUSTAINABLE RICE PRODUCTION IN THE NEAR EAST REGION

Definitions
Agricultural sustainability has been defined and described in many ways, always pointing to one dynamic concept: the growing need for agricultural production should be catered to without degrading the natural resource base on which agriculture depends. Sustainable agriculture can evolve indefinitely towards greater human utility, greater efficiency of resources and a balance with the environment that is favourable to mankind and other species.

Several concerns must be addressed:
- Food production must continue to increase in order to meet the demand of rapidly expanding populations (about 2 percent per year).
- Total agricultural employment as well as individual income from agriculture must expand.
- Efficiency in use of capital, land and production inputs must increase sustainability.
- Production systems must be structured to maintain the lowest possible use of pesticides.

Sustainability factors
A sustainable production system depends on four major areas:
- Government policy
- Improved technology
- External support
- Farmer participation

Government policy
Political stability and commitment (from government ministers through to village leaders) are important for sustainable production, through the establishment of
various facilities, the allocation of budget and step-by-step follow-up to the implementation of programmes. A focused national strategy with clear production goals and objectives will further advance sustainable improvements in rice production.

Improved research and technology
Improvement in research related to the social and economic aspects of production technology:

- Breeding high-yielding, early-maturing varieties with resistance to the major diseases and insect pests.
- Crop management to maximize yield of improved varieties and increase efficiency of irrigation water and fertilizers.
- Integrated pest management to control weeds, diseases and insects.

External support
Marketing inputs and outputs has an immense effect on sustainable rice-based systems. The floor and ceiling prices must be determined and announced well before harvesting, and inputs (e.g. seeds and fertilizer) must be made available to farmers at the appropriate time.

Farmer participation
Farmer participation and acceptance of new technologies is of course the most important factor affecting the success of sustainable rice-based systems.

CHALLENGES AND OPPORTUNITIES
Constraints in the Near East and North Africa region include: shrinking water resources; deteriorating soil health due to excessive nutrient mining and salinization; low production growth coupled with high population growth; and continued dependence on imports. The development and use of high-yielding varieties and more efficient crop management techniques will increase productivity, cost effectiveness and ecological security.

By virtue of agroclimatic advantages, such as intensive sunlight and an arid/semi-arid environment, the Near East is a potentially high-producing region. If efforts to narrow the yield gap are coupled with efficient use of resources, the region can be made truly food secure.
The sustainable development of rice-based production systems in Europe

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INTRODUCTION

Rice is not a major food crop in Europe; nevertheless, rice consumption slowly but steadily increased from 1992 to 2001. The total quantity of rice consumed as food in Europe rose from about 4.15 million tonnes of paddy equivalent in 1992 to about 4.77 million tonnes in 2001. The quantity of rice consumed in the Russian Federation in 2001 was 0.96 million tonnes, followed by Spain (0.52 million), Italy (0.48 million), Germany (0.46 million), France (0.44 million) and Portugal (0.27 million) (FAO, 2003).

Rice was introduced into Europe during the fifteenth century and – despite the low rate of rice consumption and a number of unfavourable economic and social factors – production continued. Given the relatively high production costs in Europe, it is hard to compete with imported rice. In addition, the population expresses increasing concern about the possible negative effects of rice production on the environment and on biodiversity.

However, the existing rice-based production systems present a number of opportunities for sustainable development. This paper provides a brief description of the rice production systems in Europe and discusses the agronomic constraints of and opportunities for the sustainable development of rice-based systems.

THE EVOLUTION OF RICE PRODUCTION

From 1992 to 2002, rice harvested area in Western Europe increased slightly from 350 000 ha in 1992 to about 420 000 ha in 1996, after which it decreased slightly in 1998 and then remained unchanged at about 400 000 ha until 2002 (Figure 1). Within Europe, the changes in the harvested area were pronounced in Greece and Spain. Rice harvested area in Greece increased rapidly between 1992 and 1997 and then experienced a rapid decline; in Spain, on the other hand, it decreased (from 1992 to 1995), increased in 1996 and then remained unchanged.

Rice harvested area in Eastern Europe declined rapidly from about 330 000 ha in 1992 to about 200 000 ha in 1996 and then remained stable for the rest of the period from 1992 to 2002 (Figure 1).

Table 1 shows the rice harvested area, yield and production in selected countries in Europe in 2002, when Western Europe (WE) produced 2.60 million and Eastern Europe (EE) only 0.59 million tonnes. However, the three top rice producers were Italy (WE), Spain (WE) and the Russian Federation (EE). Together, they contributed about 83 percent of the total rice production in Europe in 2002.

The data in Table 1 show that, in general, rice yields in Western Europe were much higher than in Eastern Europe. Within Western Europe, rice yield was highest in Greece and Spain. In Eastern Europe, yield was highest in Macedonia, which may be because of the more favourable climate. The data in Figure 2 show the evolution of rice yields in the two regions of Europe between 1992 and 2002. Rice yield in Western Europe increased steadily from 6 tonnes/ha at the beginning of the period to about 6.5 tonnes/ha at the end of the period. In Eastern Europe, rice yield remained stagnant at around 3 tonnes/ha from 1992 to 1999, finally increasing to about 3.5 tonnes/ha in 2000.

<table>
<thead>
<tr>
<th>Harvested area (ha)</th>
<th>Yield (kg/ha)</th>
<th>Production (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy 223 000</td>
<td>6 148</td>
<td>1 371 000</td>
</tr>
<tr>
<td>Spain 112 900</td>
<td>7 225</td>
<td>815 700</td>
</tr>
<tr>
<td>France 19 000</td>
<td>5 526</td>
<td>105 000</td>
</tr>
<tr>
<td>Greece 22 413</td>
<td>7 451</td>
<td>167 000</td>
</tr>
<tr>
<td>Portugal 24 000</td>
<td>6 041</td>
<td>145 000</td>
</tr>
</tbody>
</table>

Table 1: Rice harvested area, yield and production in Europe, 2002

FIGURE 1
Evolution of rice harvested area in Europe, 1992–2002


FIGURE 2
Evolution of rice yield in Europe, 1992–2002

RICE PRODUCTION SYSTEMS IN EUROPE

According to the FAO classification (FAO, 1996), the primary climate in Western Europe is subtropical with a dry summer (Mediterranean climate), while the primary climate of rice production in most of Eastern Europe is temperate continental. In most of Western Europe, the main rainfall occurs during the first stages of growth (April–June) and during the harvest period. Average temperatures range from 10° to 12°C during rice germination and from 20° to 25°C during crop flowering. In most of Eastern Europe, the rice-growing season is much shorter than in Western Europe, due to the low temperature regimes. The Mediterranean climate is characterized by warm, dry, clear days and a long growing season. This climate is favourable for high photosynthetic rates and high rice yields, while its low relative humidity throughout the growing season reduces the development, severity and importance of rice diseases.

About 80 percent of the rice area is cultivated with *japonica* varieties. The remainder is cultivated with *indica* varieties (mainly “Thaibonnet” and “Gladio”). Rice is planted from mid-April to the end of May and harvested from mid-September to the end of October. Rice is usually grown on fine-textured, poorly drained soils with impervious hardpans or claypans. These soils are primarily in three textural classes: clay, clay with silt, and loam with clay and silt (each ranging from 8 to 55 percent clay). A few of the soils are loam in the surface horizon, but are underlain with hardpans. The pH is between 4 and 8, with organic matter between 0.5 and 10 percent (this last value only on a limited surface area). These soils are well suited for rice production. The low water permeability enhances water-use efficiency. In some regions (the Camargue in France, Ebro Delta in Spain etc.), soils are saline or very saline. Most of the irrigation water for European rice comes from rivers (Po in Italy, Ebro in Spain, Rhone in France, Tejo in Portugal etc.) and lakes. It is estimated that less than 5 percent of rice irrigation water is pumped from wells (areas where surface water is not available or where supplement water is required). The quality of the surface water and most groundwater is excellent for rice irrigation.

In all European countries, rice is cultivated with permanent flooding. Seed beds are commonly prepared by ploughing in autumn right after the harvest of the previous rice crop or in spring of the following year at a depth of 20 cm to incorporate the residues from the previous crop into the soil. The soil is sometimes prepared by adopting minimum tillage practices to favour weed germination in order to control them better. Precision land grading, obtained with laser-directed equipment, is an agronomic practice that has greatly contributed to better water management, and consequently to increased crop-stand establishment and improved weed control. Since the beginning of the 1960s, rice has been seeded mechanically.

In general, rice seeds are mechanically broadcasted in flooded fields. However, in about 40 000 ha, mostly in Italy, seeds are drilled to dry soil in rows. In wet-seeded rice systems, soil is dried for short periods of time after the emergence of rice seedlings to promote rice rooting and to facilitate weed control treatments. However, the rice that was planted in dry soil is generally managed as a dry crop until it reaches the 3- to 4-leaf stage. After this period, the rice is flooded continually, as in the conventional system. In these conditions, rice has no competitive growth advantage over weeds, which can compete with the crop from the beginning of stand establishment.

The conventional irrigation system for rice production is known as a “flow-through” system. Water is usually supplied and regulated through a series of floodgates from the top-most to the bottom-most basin. Throughout the rice cultivation period, water is commonly kept at a depth of 4 to 8 cm, and drained away 2 to 3 times during the season to improve crop rooting, reduce algae growth and allow application of herbicides. Rice fields are commonly drained towards the end of August to allow harvesting.

Fertilization of the soil aims principally to restore the main plant nutrients removed by crops. Under flood conditions, nitrogen is primarily absorbed in its ammonium form. This nutrient is commonly supplied at a rate of 80 to 120 kg/ha (50 percent in pre-planting and 50 percent in post-planting), using urea or other ammonium-based fertilizers. Phosphorous and potassium are supplied in the pre-planting stage at rates of 50 to 70 and 100 to 150 kg/ha, respectively.

THE EUROPEAN RICE MARKET

The European rice market consists of long-grain *indica* rice and round- to medium-grain *japonica* rice. While Europeans have traditionally consumed mostly *japonica* rice, the consumption of *indica* rice has been increasing in recent years. Demand in north European countries is almost entirely for *indica* type grains. Consumption of *indica* rice has surpassed that of *japonica* rice since 1999/2000.
European rice consumption is divided between human consumption (85 percent), animal feed (7 percent), industry (3 percent), seeds (3 percent) and loss (5 percent). Human consumption has increased, while other uses are stable or decreasing (industry) (CEC, 2002). European Union (EU) consumption of milled rice equivalent (industrial uses included) reached 1.8 million tonnes for the 2000/01 marketing year (CEC, 2002). The trend in consumption of milled rice equivalent is up and reached about 5 kg per caput in 2002.

Rice produced in southern Europe is processed by the local food industry in response to the demand of Mediterranean consumers and the demand for export to northern Europe. In addition to imports from southern Europe, the food-processing industry in the north imports indica husked rice from the United States of America, Thailand, India and Pakistan. Imports have increased since 1994/95 as a consequence of the Uruguay Round, the subsequent reduction of the Basmati rice tariff and the implementation of preferential regimes. The quantity of imports from third countries, expressed in milled equivalent, rose by 30 percent from 1995 to 2000. Over the same period, exports fell by 11 percent. Since then, however, total exports have stabilized, and food aid operations have at least partially replaced commercial exports (CEC, 2002). However, according to data collected between 1997/98 and 1999/2000, internal trade quantities were twice those of external trade. Italy is the main provider (about 300 000 tonnes of milled rice equivalent), followed by Spain (about 150 000 tonnes of milled rice equivalent).

Market liberalization for rice will be applied starting in 2009. Tariff reductions will be phased in with a 20 percent cut in 2006, 50 percent in 2007 and 80 percent in 2008. In the meantime, a duty-free quota, based on previous exports to the EU, has been established, with an increase of 15 percent each year until 2009, when all tariffs and quotas will be removed. This liberalization policy was agreed upon after the introduction of the European Commission agreement of February 2001. The agreement grants duty-free access to the EU market for imports from least developed countries (LDCs) for everything but arms (EBA).

On 26 June 2003, EU agriculture ministers agreed on fundamental reforms to Common Agricultural Policy (CAP), a break in the link between subsidy and production and an allowance of preparation for full implementation of EBA from 2009. The primary aspects of CAP reform concerning rice aim to reduce the intervention price by 50 percent, limiting the amount to 75 000 tonnes per year. These reductions are compensated for by a subsidy devoted in part to environmental protection.

**RICE PRODUCTION CONSTRAINTS**

The most significant constraints to rice production in Mediterranean climate areas include: low temperature, water scarcity, biotic stresses, unsatisfactory grain quality, high production costs and the population’s concern about the harmful effects of rice production on the environment.

**Low temperature**

As rice plants originate from subtropical and tropical zones, they are easily damaged by low temperatures at any growth stage from germination to ripening (Ferrero and Tabacchi, 2002). Several experiments point out that a potential yield of 10 tonnes/ha requires a density of at least 250 seedlings per m². The cool weather and strong winds during stand establishment in Mediterranean climate areas may cause partial stand loss and seedling drift, which lead to poor crop establishment. In many temperate areas, the emergence rate quite often does not exceed 30 to 40 percent of the planted seeds. Therefore, to achieve an acceptable crop stand, rice growers usually use about 200 kg/ha of seed.

This low rate of crop emergence is due primarily to the effect of anaerobic conditions on germination occurring under low temperatures. To avoid low temperatures during crop establishment stage, some growers end up with delays in crop planting. However, a delay in crop establishment leads to the occurrence of reproductive stages of the crop during periods of low temperatures during the autumn that causes the death of pollen cells at meiosis stage and subsequent grain sterility. Damage to rice yield caused by spikelet sterility could be one of the most severe in years.

Poor crop establishment under European conditions could be overcome by developing new high-yielding varieties with good tolerance to low temperatures during germination, better land levelling and water management.

**Water scarcity**

Water is becoming increasingly scarce in many regions of the world. Between 1700 and 2000, total worldwide water withdrawal increased more than 35 times the rate of population increase. Governments will be compelled to place severe limitations on the use of water resources,
particularly in agriculture. Agriculture is by far the biggest consumer of water. Water consumption in agriculture represents about 40 percent of the total consumption in Europe, 50 percent in North and Central America and 85 percent in Asia. In the short term, the conflicting demand for water for use in industrial activities, sanitation and as safe drinking water can be expected to increase.

Many water problems are related to its uneven distribution. Other problems include pesticide pollution, soil erosion and deforestation, waterlogging in heavy soils, and increasing irrigation costs. All these constraints are forcing agronomists to develop management strategies to reduce water consumption and increase the efficiency of irrigation systems. As a result, agronomists are continually creating strategies that increase the rice yield per unit of water input. According to the estimates of the World Resources Institute, 15 percent of the water losses due to evaporation, leaching or any other inefficiency can be saved through more sensible use. Water problems can also be tackled by providing new rice varieties which are more suitable to the various conditions of water management.

Rice is more water-consuming than many other crops: in continuous flooding cultivation it consumes about six times the water required by wheat. New varieties suitable for reduced water use are needed in irrigated systems. The availability of short-cycle and high-yielding rice could successfully lower the amount of irrigation water used in continuously flooded cultivation. A more consistent reduction in water consumption could be achieved by developing profitable varieties suitable for discontinuous irrigation in all climate conditions. These conditions of water management will also contribute to the alleviation of methane emissions from rice. Non-flooded conditions, however, can lead to increased competition from weeds and increased soil salinity. The constraints on rice yield caused by weed growth and soil salinity must also be addressed as new varieties are developed.

Biotic stresses
According to Oerke et al. (1994), rice losses caused by disease, pests and weeds, despite current crop protection, account for about 50 percent of the crop potential. The numerous experiments conducted each year in European rice paddies reveal that the failure to control weeds may potentially result in the complete loss of the rice yield. The main noxious rice organisms are:

- blast (*Pyricularia oryzae*) and stem rot (*Rhizoctonia oryza-sativae*) (diseases);
- rice leafminer (*Hydrellia griseaola*) and tadpole shrimp (*Criops longicaudatus*) (animal pests); and
- *Echinochloa* spp., *Bolboschoenus maritimus*, *Schoenoplectus mucronatus*, *Heteranthera* spp., *Alisma plantago-aquatica* and weedy rice forms (weeds).

All these species are usually controlled with pesticides. The use of these products may, however, result in the appearance of resistant species, cause environmental pollution and risk disrupting the precarious balance of the natural enemies to pests (Ferrero et al., 2001; Ferrero, Tabacchi and Vidotto, 2002).

Weed resistance to herbicides has been reported in Italy, Spain, France and Greece. For example, a few years after the introduction of sulfonylurea herbicides, some species began to develop resistance to acetolactate synthase inhibitors. This phenomenon was first noticed in 1995 in *A. plantago aquatica* and *S. mucronatus* plants, and was continuously treated for at least 3 years. The studies of Sattin et al. (1999) on *S. mucronatus* have shown that there is a cross-resistance among several sulfonylureas (azimsulfuron, bensulfuron-methyl, cynosulfuron and ethoxysulfuron). Some of these resistant populations appeared to be sensitive to triazolopyrimidine herbicide (metosulam) at very high dosages (three times the recommended field dose). In Italy, weed resistance was reported on a rice surface of more than 15,000 ha (Ferrero, Tabacchi and Vidotto, 2002).

A solution to these issues could be the development of rice cultivars that are resistant to pests and diseases, highly competitive against weeds, with allelopathic traits, and tolerant to safe and wide spectrum herbicides (Ferrero et al., 2001). The use of these varieties combined with prophylactic measures could be a sound strategy for preventing damage.

Grain quality
The quality of rice is not always easy to define as it depends on a combination of many subjective and objective factors, largely related to the consumer and the intended end use of the grain. The demand by the consumer for better quality has notably increased in the more economically developed countries of Europe, giving rice producers the opportunity to increase the total economic value of rice. Quality traits are also related to
the taste of the several ethnic groups that make up European society.

Grain quality is influenced either by characteristics of variety or the crop production environment, harvesting, processing and milling techniques. The main key components of rice quality are listed in Table 2. Some of these have also been defined by EC (European Community) regulations, which have recently come into force. The regulations relate to the common organization of the rice market.

Many characteristics of grain quality are related to rice grain shape. Since rice is consumed in grain form, the physical dimensions and weight are among the first criteria of rice quality that breeders consider when developing new varieties. Grain type categories are based upon three physical traits: length, width and weight. According to EC regulations, only length and width and their ratio are formally considered. In the United States of America, however, grain weight is also taken into consideration (Table 3). Long slender grains usually have greater breakage than short grains and consequently give a lower milling yield.

The demand for long-grain varieties increased significantly as a result of food diversification and immigration (Tran, 1996). The EC further encouraged this demand through the allocation of subsidies to rice growers planting indica type rice. Subsidies were originally given to compensate for lower paddy and milling yields. The variety was often recorded in comparison to japonica varieties. To meet this demand, many long-grain varieties have been introduced in European countries. All these varieties are suited to temperate climatic conditions even if they are sometimes damaged by low night temperatures, occurring particularly during the flowering period (Ferrero, Tabacchi and Vidotto, 2002).

Grain shape is usually associated with specific cooking characteristics. Cooked long-grain rice is fluffy and firm, while medium and short-grain rice is soft, moist and sticky in texture. The demand among consumers in Europe is higher for long-grain rice.

Grain fissuring is often due to overexposure of mature paddy to fluctuating temperature and moisture conditions. Cracks in the kernel are the most common cause of rice breakage during milling. Milling degree is influenced by grain hardness, size and shape, depth of surface ridges, bran thickness and mill efficiency. Wholegrain milling yield is the percentage of intact kernels to broken kernels after milling and separation. Producers are paid less for broken kernels than for whole.

Other specific quality traits are usually required for the production of processed rice, such as parboiled, quick cooking or precooked rice and rice flour. Rice parboiled for consumption as table rice is generally a long-grain

<table>
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<tr>
<th>TABLE 2</th>
<th>Main components of rice quality in Europe</th>
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<tr>
<td>Component of rice quality considered by</td>
<td>Other components of rice quality</td>
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<tr>
<td>EC regulation 1785/2003</td>
<td></td>
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<tr>
<td>Grain shape</td>
<td>Milling quality</td>
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<tr>
<td>Colour of the grains (green, chalky, striated,</td>
<td>Cooking and processing</td>
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<td>spotted, stained, yellow, amber)</td>
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<td>Grain integrity (malformed and clipped or</td>
<td>Grain fissuring</td>
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<td>broken grains)</td>
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<tr>
<th>TABLE 3</th>
<th>Range of grain size among typical European and United States long-, medium- and short-grain rice</th>
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<tr>
<td>Type</td>
<td>EC regulation</td>
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<td>Long:</td>
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<td>· Long A</td>
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<td>· Long B</td>
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<tr>
<td>Medium</td>
<td>&gt;5.2</td>
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<td>Short</td>
<td>&lt;5.2</td>
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variety. Medium-grain rice is also parboiled, but it is more commonly ground into flour for use as an ingredient in food products (baked crackers, fried snacks).

Aroma is an important qualitative trait in specific varieties (Basmati type). Rice of this type is generally long-grain with high grain quality. It has an aroma often described as being “popcorn-like”. The grains become very long and thin and maintain a moderately firm texture after cooking. Demand for aromatic rice varieties has shown a significant increase since the early 1990s, primarily in the United Kingdom and other European countries, but also with a significant presence in Asiatic communities, (Faure and Mazaud, 1996). It seems reasonable to expect a further increase in aromatic rice consumption throughout Europe in the years to come, because of the increase in people migrating from Far East countries and the growing interest in ethnic cuisine. European consumption of Basmati rice is met entirely by imports from India and Pakistan. For this reason, specific research programmes need to be set up in order to develop aromatic varieties suited to European climatic conditions.

European consumers are showing a growing interest in special rice varieties, such as organic rice, waxy rice, Jasmine-type rice, wild rice and coloured (red, black) pericarp. At present, the demand for these products only accounts for a small share of the market, with the exception of organic rice. Organic rice has already found a place in market demand, and its demand is expected to increase in the short to medium term. The yield obtained in organic rice systems is usually 25 to 30 percent lower than that obtained in ordinary cultivation, mainly because of the great difficulty in controlling weed infestations.

Lodging resistance has been a key target trait for raising yield potential. It is associated with traits such as plant height, stem strength and thickness. Lodging-resistant rice cultivars usually show slow grain filling when nitrogen is applied in large amounts. Many other problems, such as variable milling yield, grain fissuring, grain shedding and non-contemporaneous maturity, are sometimes closely linked to the genetic features of the rice varieties, and are also related to other agronomic constraints, such as cold temperature and lodging.

High production costs
The cost of rice production in Western Europe is generally much higher than in most Asian countries, with the exception of Japan. The production cost per tonne of paddy rice in Europe is also higher than in the United States of America. The high production cost in Europe compared with the United States of America was largely due to the high expenses relating to fertilizer, seed, crop protection products, custom application, fuel and labour. The cost of production in the United States of America can range from US$104 to 180 per tonne (Salassi, 2002), while in Italy the cost is about €200 per tonne (AIDAF-VC/BI, 2003).

Population’s concern
The increase in number of mosquitoes and concern for the spread of malaria was a major reason for the restriction of rice production in the past. There is increasing concern related to the negative effects of rice production on the environment (especially the emission of methane gases which cause global warming) and the harmful effects of pesticide application on agricultural biodiversity in rice-based production systems. This new concern may lead to further restrictions in rice production in the continent. Integrated management systems for efficiency in input utilization, including the use of water, need to be promoted in rice production in Europe. Also, the promotion of agricultural biodiversity in rice-based production systems, such as rice-livestock and rice-other crops, is desirable.

OPPORTUNITIES FOR SUSTAINABLE RICE PRODUCTION
One of the most effective means of addressing the issues in rice cultivation and raising the average yield at farm level is through research and subsequent dissemination of the resulting data. Numerous research programmes at national or European level have been set up throughout Europe. They cover the whole rice sector, from agronomic practices and breeding aspects to quality and market problems. Much of the research done in Europe has been fostered by MED-RICE (Inter-regional Cooperative Research Network on Rice in the Mediterranean Areas).

Advances in rice research
Rice science has made considerable progress. In the area of rice varietal improvement, recent advances in hybrid rice and new rice for Africa (NERICA) are just two examples of the successful contributions of science to the development of rice. Scientists at IRRI have continued working to increase the genetic yield potential of tropical rice through the concept of new plant types (NPT) with the stated goal of increasing the yield potential to between 12 and 15 tonnes/ha (Fisher, 1996; Peng, Khush and...
Cassman, 1994). The recent success in rice genome mapping has further increased the potential for the application of science. The increase in the yield potential of rice, the tolerance/resistance of rice to disease, weeds and pests, as well as tolerance to drought and salinity, could be achieved without harming the environment (Khush and Brar, 2002). However, these opportunities have also created new imperatives for biosafety, field-testing and capacity-building within nations to ensure that the new innovations benefit local people and do not incur long-term costs to the environment.

Most existing rice varieties have a potential yield that exceeds actual yield. Furthermore, there is considerable variation in the actual yield levels achieved even under similar production systems. The gap reflects numerous deficiencies resulting primarily from inadequate crop, nutrient and water management practices. During the 1990s, several systems were developed to allow a higher level of integrated crop management practices in rice production. The application of these rice integrated crop management (RICM) systems has increased rice yield and reduced cost and environmental degradation through more efficient application of inputs. From 1973 to 1985, rice yield in Australia remained stagnant at around 6 tonnes/ha. The RICM system, “RiceCheck”, was developed and transferred in 1986 (Clampett, Williams and Lacy, 2001). With the wide adoption of RiceCheck, the Australian national yield increased rapidly and steadily from about 6 tonnes/ha in 1987 to 9.65 tonnes/ha in 2000 (Figure 3). According to Australian rice scientists, half of the observed yield increase since 1986 can be attributed to the adoption of new rice varieties and another half to the adoption of RiceCheck (Nguyen, 2002). The development and dissemination of RICM systems in Europe could help to lower production costs per tonne of paddy and to minimize environmental degradation.

FIGURE 3

MED-RICE

Rice cultivation in Mediterranean climate areas has had to face strong competition in the world market. In the local market, demand for speciality and quality rice has become more and more common. To tackle these challenges, institutions from Europe and the Near East have improved scientific cooperation while trying to capitalize on the wide range of experience and potential in each country.

Relationships among rice scientists from many of the countries with a Mediterranean climate are strengthened through scientific gatherings sponsored by the Inter-regional Cooperative Research Network on Rice in the Mediterranean Areas. The network, known as MED-RICE, began as a response to the need for collaboration and coordination in research on rice in view of its increasing cultivation and consumption in Europe. Some of the issues dealt with include:

- the quality and competition of European rice;
- resistance to blast, water shortage, stem borers and disease;
- control of red rice;
- cataloguing of rice genetic resources in the region; and
- a data bank of knowledge on all aspects of rice cultivation for the purpose of improved management and rice yields.

These issues are all being addressed through cooperative research programmes between member institutions of the network. Sixteen countries participate in MED-RICE: Bulgaria, Egypt, France, Greece, Hungary, the Islamic Republic of Iran, Italy, Morocco, Portugal, Romania, the Russian Federation, Spain, Turkey, the United Kingdom, Ukraine and Uzbekistan. MED-RICE activities include scientific meetings, cooperative research programmes and publications, ranging from reports and proceedings to a newsletter (Medoryzae). The network’s Web site can be found at http://medrice.agraria.unito.it

CONCLUSIONS

Rice is not among the major food crops of Europe; however, rice consumption as food is slowly but steadily increasing. Since its introduction, rice production has remained in Europe, despite the low rate of rice consumption and a number of unfavourable economic and social conditions. The cost of rice production in Europe remains relatively high, making competition with imported rice difficult. In addition, concern over the negative effects of rice production on the environment and biodiversity has continued to increase. However, the rice-based production systems in Europe have a number of opportunities for sustainable development.

A sustainable increase in rice production in Europe and North Africa requires strategies that must focus on the following:

- Collaboration among rice research institutions towards the adoption of modern plant breeding technology to develop new generations of high-yielding varieties with better grain quality and with better resistance or tolerance to biotic and abiotic stresses.
- Promotion and development of rice integrated crop management (RICM) systems for improving productivity and reducing the production cost per unit of output.
- Promotion and adoption of production technologies and systems that aid the conservation of biodiversity and the environment.

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