Rice Production

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Rice

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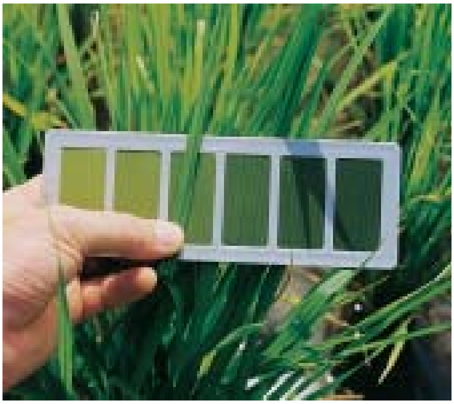
Better Crops International



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Rice in the Global Food Supply

By T.H. Fairhurst and A. Dobermann

Rice (*Oryza sativa* L.) has supported a greater number of people for a longer period of time than any other crop since it was domesticated between 8,000 to 10,000 years ago (Greenland, 1997). At present, rice is the staple food for more people than wheat, and 90 percent of total rice production is grown and consumed in Asia (Evans, 1998). Unlike maize or wheat, less than five percent of total rice production is traded on world markets, mainly within Asia and from Asia to Africa and Europe. Thus the emphasis in all rice economies is on self-sufficiency. In many Asian countries, rice self-sufficiency and political stability are interdependent issues.

Wetland or paddy rice production has been sustained over millennia and can be considered one of the world's most sustainable and productive farming systems. On an annual basis, irrigated rice is often 100 times more productive than upland rice, over 12 times more productive than deep-water rice, and five times more productive than rainfed rice (**Table 1**). Irrigated rice accounts for 55 percent of the global harvested area and contributes 75 percent of global rice production, which is about 410 million tonnes (M t) of rice per year (Dobermann and Fairhurst, 2000). Rice is now the staple food of 2.7 billion people, almost half the world's population, and is grown by more than half the world's farmers. The enormous productivity of intensified paddy rice systems accounts for the very high population densities and rich cultures that have developed alongside the major river systems of Asia. Rice culture is thus the cornerstone of cultural, social, and economic development in Asia.

Until the middle part of the last century, yields increased slowly but steadily and crop failure became less frequent as improved methods to control water supply were developed and farmers selected varieties adapted to specific agroecological conditions. Rice was adapted to fit a wide range of growing conditions, from the equatorial tropics to the high altitudes of Japan, from the tropical lowlands to the mountain terraces of the Himalayas, and from deep-water swamps to the uplands. This explains why over the past 35 years it has been possible to collect more than 80,000 local varieties now

Table 1. Comparison of the productivity of four different rice systems (von Uexküll, 1996).

System	Yield, t/ha	Crops/yr	Fallow period	Productivity, t/ha/yr
Irrigated rice	5.0	2.5	0	12.5
Deep water rice	1.0	1	0	1.0
Rainfed rice	2.5	1	0	2.5
Upland rice[1]	1.0	1	8	0.12

[1] Grown in slash and burn systems where long bush fallow periods between rice crops are required to replenish soil fertility.

Table 2. Population, total rice consumption, and per capita milled rice consumption (IRRI, 2001).

	Population, million		Rice consumption, '000 t rough rice equivalent		Milled rice consumption, kg milled rice/capita/yr	
	1998	2020	1990	1998	1990	1998
Asia	3,585	4,545	413,723	464,143	88.9	86.6
Latin America	504	665	16,998	18,271	26	24.5
Africa	749	1,187	15,129	20,269	16.5	18.1
Europe	729	712	2,781	4,296	3.7	3.9
Australia	18	22	170	258	6.8	9.3
U.S.	274	317	2,595	3,679	6.8	9.0
World	5,901	7,502	454,349	511,675	57.5	58.1

stored at the International Rice Research Institute (IRRI) germplasm collection.

Change in demand for rice is driven by population growth, level of per capita income, and changes in the price of rice relative to substitute crops (Hossain, 1997). Another factor may be the effect of recent increases in body size on per capita food requirements in much of Asia (von Uexküll, 1996). Worldwide, rice consumption increased by almost 60 M t (about 12.5 percent) between 1990-1998 (**Table 2**).

Table 3. Changes in rice trade, 1990-1998 (after IRRI, 2001).

	'000 t milled rice					
	1990			1998		
	Imports	Exports	Balance	Imports	Exports	Balance
Asia	4,834	7,765	+2,931	15,398	21,311	+5,913
Latin America	1,479	584	-895	3,428	1,765	-1,663
Africa	3,062	101	-2,961	4,723	450	-4,273
Europe	1,931	1,087	-844	2,614	1,413	-1,201
Australia	27	424	+397	37	552	+515
U.S.	148	2,474	+2,326	279	3,113	+2,834
World	12,184	12,471	+287	27,040	28,605	+1,565

Increases in consumption were driven mainly by population growth in Asia, Latin America, and Africa, and by increased per capita consumption in Europe, Australia, and North America. A positive trade balance for rice has been maintained by Asia, Australia, and the U.S. (**Table 3**) whilst deficits have increased in Latin America, Africa, and Europe.

An increase in total production may result from an increase in the area planted, increased yields, and increased cropping intensity. Worldwide, both area expansion and yield increases contributed equally to the increase in rice production of almost 80 M t between 1990 and 1998. In Africa, Europe, and the U.S., more than 80 percent of increased production was explained by an increase in the area planted. The largest increases in yield were in Latin America...about 44 percent...and Australia, 15 percent (**Table 4**).

Until the early 1960s and before the introduction of herbicides, tall varieties were preferred because they gave rice a competitive advantage against weeds. Also, tallness was an advantage because farmers valued rice straw for use as fuel, animal bedding, mulch, and because tall rice plants were considered easier to harvest.

Improvements in nitrogen (N) fertilizer manufacturing technology led to dramatic decreases in the cost of N in the late 1950s, but tall rice varieties were poorly responsive to N fertilizer due to their susceptibility to lodging. Improvements in crop protection, herbicides, and water control, combined with the advent of cost effective N fertilizers, led

Table 4. Rice production, area, and yield (after IRRI, 2001).

	Production, '000 t		Area, '000 ha		Yield, t/ha	
	1990	1998	1990	1998	1990	1998
Asia	479,480	540,621	132,328	138,503	3.6	3.9
Latin America	15,565	24,045	6,183	6,611	2.5	3.6
Africa	12,407	17,602	6,099	7,842	2.0	2.2
Europe	2,404	3,238	449	581	5.4	5.6
Australia	924	1,410	105	140	8.8	10.1
North America	7,080	9,546	1,142	1,442	6.2	6.6
World	520,053	596,485	146,933	155,128	3.5	3.8

breeders to select plants with short, stiff straw that were less prone to lodging and produced a larger harvest index (the ratio of grain to total above-ground biomass production).

Perhaps the single most momentous event in the history of rice production was the crossing of the Taiwanese variety Dee-geo-woo-gen with the Indonesian variety Peta to produce IR8, which, with its release in 1966, began the Green Revolution. Since then, there have been spectacular increases in grain yields. With support from international lending agencies, local governments have made major investments to improve water control in irrigated rice systems that have led to greater cropping intensity (crops/ha/yr) and an increase in the area planted to rice. The combined effect of these changes has allowed rice production to keep pace with the dramatic increase in demand driven by increases in world population over the past 30 years.

The factor that has contributed most to exploiting the yield potential of modern varieties, however, has been the increase in the use of N fertilizers. In most locations, increased use of phosphorus (P) fertilizers was also required before a substantial response to N could be obtained. In countries with large deposits of oil and natural gas, these energy resources are used to manufacture N fertilizers. Manufactured P fertilizers are either imported or produced from local or imported phosphate rock and sulfuric acid and/or phosphoric acid.

In contrast to N and P, potassium (K) fertilizer has been used only sparingly in Asia's rice fields. Several studies have reported large negative balances for K and a depletion of soil K reserves. In a nutrient balance calculation for a typical rice-rice-bean rotation, the overall balance for N and P is positive. By contrast, whilst the relatively small percolation losses of K are balanced by additions in rainfall and irrigation water, 42 kg K_2O/ha is required to replace K removed in grain, and 235 kg K_2O/ha must be added if both the straw and grain are removed from the field (Greenland, 1997). Fertilizer K is now considered a key production factor in many areas as a result of past soil mining, and straw removal for industrial use. There is also a growing body of evidence on the importance of K in plant health and pest resistance.

Rice accounts for more than 40 percent of caloric intake in tropical Asia, reaching more than 65 percent in many countries and for many poor people. It also accounts for more than 60 percent of protein consumption in countries such as Bangladesh and Myanmar, and from 30 to 40 percent in Indonesia, Thailand, and the Philippines. Furthermore, rice production accounts for more than 25 percent of gross domestic product (GDP) in countries such as Vietnam and Bangladesh. Yields must continue to increase by 1 percent per annum until 2020 (Rosegrant et al., 1995) to keep up with demand. Rapid growth in rice production in Asia will help to alleviate poverty because faster growth leads to lower rice prices for poor rural and urban consumers. In addition, lower rice prices will encourage farmers to diversify into higher valued crops and thus provide more income for farmers and improved nutrition for consumers (Dawe, 2000).

There is very little opportunity to increase the area planted to rice and further crop intensification is constrained by limited supplies of water. Therefore, the increase in supply must mainly be met by increasing crop yields through better crop, nutrient, pest, and water management and the use of germplasm with a higher yield potential. Such approaches require much greater farmer knowledge. A major challenge during the coming decade is to develop cost effective technology transfer methods to increase the ability of farmers to manage the resources at their disposal more efficiently. **BCI**

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Rice Straw Management

By A. Dobermann and T.H. Fairhurst

Straw is the only organic material available in significant quantities to most rice farmers. About 40 percent of the nitrogen (N), 30 to 35 percent of the phosphorus (P), 80 to 85 percent of the potassium (K), and 40 to 50 percent of the sulfur (S) taken up by rice remains in vegetative plant parts at crop maturity.

Straw is either removed from the field, burned *in situ*, piled or spread in the field, incorporated in the soil, or used as mulch for the following crop. Each of these measures has a different effect on overall nutrient balance and long-term soil fertility. Where S-free mineral fertilizers are used, straw may be an important source of S; thus, straw burning should not be practiced. In contrast, burning effectively transforms straw into a mineral K nutrient source, and only a relatively small amount of K is lost in the process. The effect of straw removal on long-term soil fertility is much greater for K than for P (**Table 1**). Spreading and incorporation of straw, however, are labour-intensive tasks, and farmers consider burning to be more expedient. Straw is also an important source of micronutrients such as zinc (Zn) and the most important influence on the cumulative silicon (Si) balance in rice.

Straw Removal

Removal of straw from the field is widespread in India, Bangladesh, and Nepal, which explains the depletion of soil K and Si reserves at many sites. Straw can be used as fuel for cooking, ruminant fodder, and stable bedding or as a raw material in industrial processes (e.g., papermaking). In the process, some or all of the nutrients contained in straw may be lost to the rice field, particularly where animal manure is used in other parts of the farming system where the response to straw application is greater than for rice.

Straw Incorporation

Incorporation of the remaining stubble and straw into the soil returns most of the nutrients and helps to conserve soil nutrient reserves in the long-term. Short-term effects on grain yield are often small (compared with straw removal or

Table 1. Nutrient content of rice straw and amounts removed with 1 tonne of straw residue.

	N	P_2O_5	K_2O	S	Si
Content in straw, % dry matter	0.5-0.8	0.16-0.27	1.4-2.0	0.05-0.10	4-7
Removal with 1 tonne straw, kg/ha	5-8	1.6-2.7	14-20	0.5-1.0	40-70

burning) but long-term benefits are significant. Where mineral fertilizers are used and straw is incorporated, reserves of soil N, P, K, and Si are maintained and may even be increased. Incorporation of straw and stubble into wet soil (during plowing) results in temporary immobilization of N and a significant increase in methane (CH_4) emission from rice paddy, a practice that contributes to greenhouse gases. Incorporation of large amounts of fresh straw is either labour-intensive or requires suitable machinery for land preparation and may result in the build-up of disease problems. Transplanting should be carried out two to three weeks after straw incorporation.

Recent research results from experimental farms indicate that early, dry shallow tillage at 5 to 10 cm depths (to incorporate crop residues and enhance soil aeration during fallow periods) has beneficial effects on soil fertility in intensive rice-rice systems. Shallow tillage of dry soil should be carried out up to two to three weeks after harvest in cropping systems where the dry-moist fallow period between two crops is at least 30 days. Beneficial effects include:

- A more complete carbon (C) turnover is achieved by aerobic decomposition of crop residues (about 50 percent of the C within 30 to 40 days), thereby minimizing negative effects (e.g., phytotoxicity) of the products of anaerobic decomposition on early rice growth.
- Improved soil aeration…i.e., reoxidation of iron (Fe^{2+}) and other reduced substances that accumulate during the flooding period.
- Increased N mineralization and soil P release to the succeeding crop, up to the panicle initiation stage.
- Reduced weed growth during the fallow period.
- Reduced irrigation water requirement during land preparation (i.e., less soil cracking and bypass flow water losses in heavy clay soils).
- Easier wetland preparation (i.e., there is often no need for a second plowing operation).
- Smaller CH_4 emissions compared with straw incorporation during land preparation for the crop.

Burning

Burning causes almost complete N loss, P losses of about 25 percent, K losses of 20 percent, and S losses of 5 to 60 percent. The amount of nutrients lost depends on the method used to burn the straw. In areas where harvesting has been mechanized (e.g., Thailand, China, and northern India), all the straw remains in the field and is rapidly burned *in situ*; therefore, losses of S, P, and K are small.

In Indonesia and the Philippines, straw is heaped into piles at threshing sites and burned after harvest. The ash is usually not spread on the field, and this results in large losses of minerals…K, Si, calcium (Ca), magnesium (Mg)…leached from the ash piles, although nutrients contained in the relatively long stubble (30 to 40 cm) remain in the field. Moreover, such a practice results in a significant transfer of nutrients from the periphery of the field to the center, or even from surrounding fields to the center field where, after threshing, the residues are burned. Over time, this practice results in the accumulation of nutrients (K, Si, Ca, Mg) in some parts of the field and nutrient depletion in other parts.

Burning causes atmospheric pollution and results in nutrient loss, but it is a cost-effective method of straw disposal and also helps reduce pest and disease populations that may occur due to reinfection from inoculum in the straw biomass.

Conclusions

An assessment of farmer straw management practices is an important part of developing fertilizer recommendations. The major impact of straw removal is on the soil K balance. Complete straw removal over several cropping seasons without replenishing soil K with mineral fertilizer is likely to lead to increased incidence of K deficiency.

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Rice Fact File

Origin—Domesticated in Africa (*Oryza glaberrima*) and Asia (*Oryza sativa*). Several centres of origin have been proposed for *O. sativa*, including India and northern Thailand. Evidence points to the Yangzi Valley in southern China as one site of origin for domesticated rice.

Botany—Rice is a grass (*Gramineae*) and belongs to the genus *Oryza* (meaning oriental). *Oryza sativa* is grown in a wide range of environments from the equatorial tropics to sub tropical mid-latitudes, from lowland paddy fields to high altitude terraces, and from swamps to upland rice fields.

Cultivars—Since the introduction of modern varieties in the 1960s, most paddy rice farmers cultivate short straw, nitrogen (N)-responsive varieties with multiple pest resistance. Local varieties are more common in upland, rainfed, and deep-water rice environments. Improved germplasm for some of these environments is now available.

Harvest part—In upland rice fields, the ripe panicle is removed with a special knife concealed in the palm of the harvester's hand, and straw is left standing. In paddy rice fields, rice is harvested with a sickle or mechanical harvester, and the panicle together with a portion of the stem is removed. The amount of stem removed depends on the threshing method used and farmer requirement for straw as livestock bedding, fuel or mulch.

Life cycle—The growing season of some traditional varieties is about 260 days, but is between 90 to 110 days for most modern varieties. Shortening the growing season is a key factor in increasing cropping intensity (crops/ha/yr). Crop maturation is extended under conditions where phosphorus (P) or other nutrients are deficient.

Maximum yield—At present, the genetic yield barrier for inbred varieties in irrigated rice systems is about 10 t/ha. Under best management practices in favourable environments, farmers are able to achieve yields of greater than 8 t/ha. To meet future food demand, short duration varieties with a yield potential of 15 t/ha will be required. Some researchers argue that the rice plant's radiation conversion factor of 2.6 to 2.9 g/MJ (megajoule) may not be sufficient to reach such yields. The possibility of incorporating C_4 plant physiological characteristics into rice to increase yield potential is presently under consideration.

Nutrient removal—Nutrient balance is strongly affected by straw management. Straw contains more than 85 percent of the potassium (K) contained in the above-ground biomass. Thus, much greater amounts of K must be applied to maintain the soil supply where straw is removed from the field. Removal of N and P is mostly associated with grain harvest.

	Nutrient removal, kg nutrient/tonne				
	N	P_2O_5	K_2O	Mg	Ca
Rice grain	10.5	4.6	3.0	1.5	0.5
Rice straw	7.0	2.3	17.5	2.0	3.5
Rice grain + straw	17.5	6.9	20.5	3.5	4.0

Micronutrient requirements—Rice often requires zinc (Zn) in alkaline soils and soils containing very large concentrations of organic matter. Copper (Cu) is usually required to prevent male sterility in rice grown on peat soils.

Fertilizer nutrient recovery efficiency—In irrigated lowland rice fields with good crop management and grain yields of 5 to 7 t/ha, typical fertilizer recovery efficiencies are 30 to 60 percent for N, 10 to 35 percent for P, and 15 to 65 percent for K. Recovery efficiency for N and K is strongly influenced by splitting and timing of fertilizer applications.

Planting density and canopy management—Optimal planting density depends on the crop establishment method and variety (tillering capacity). In transplanted rice, a plant spacing of 0.2 x 0.2 m gives 250,000 hills/ha. In direct seeded paddy rice, rates range from 60 to 80 kg seed/ha. In upland rice, seed is dibbled into evenly spaced planting points, and seed rates are lower, ranging from 30 to 35 kg/ha. Excessive early canopy development (seeding/transplanting to early tillering) may result in a very leafy canopy that is more susceptible to pest and disease infestation. Proper splitting and timing of N fertilizer applications are required to produce an optimal canopy without incurring pest and disease damage.

Climatic requirements—In paddy rice, maximum yields are obtained in the dry season, when cloud cover is less and photosynthetic active radiation (PAR) is greater than during the wet season. In irrigated rice, rainfall is not important, provided the irrigation water supply is reliable and sufficient in quantity. In rainfed and upland rice, rainfall is a major yield determinant, particularly in coarse textured soils with poor water retention.

Soil requirements—In upland and rainfed rice, soil structure and fertility are major yield determinants because the amount of mineral fertilizer used is often small. In irrigated rice, soil structure is deliberately destroyed during land preparation. The effect of flooding generally improves nutrient availability and reduces the effects of very alkaline or acid soil conditions on plant growth that occurs under aerobic conditions. In high yielding environments where modern varieties are used, the difference between the soil's indigenous nutrient supply and crop nutrient demand must be provided in the form of mineral fertilizer. **BCI**

Developments in Rice Production in Southeast Asia

By Ernst Mutert and T.H. Fairhurst

While some countries of Southeast Asia have increased productivity of rice in recent years, yields have stagnated in other countries of the region. The correlation to fertilizer nutrient use is clear, and there is great potential for increased production.

Because of its political, economic, and social significance in the eight agricultural countries of the Association of Southeast Asian Nations (ASEAN), rice remains the most important crop grown in Southeast Asia (SE Asia). The greatest levels of productivity are found in irrigated rice, where more than one crop is grown per year and yields are high (**Table 1**). Productivity is poor in upland systems where yields are small and only one crop is grown per year. Upland rice is usually grown without mineral fertilizer, and a long fallow period of at least eight years under secondary forest is required to generate soil fertility. Due to increased population pressure, such lengthy fallow periods are no longer feasible and upland rice is thus a major cause of land degradation and nutrient mining in many parts of the region.

Irrigated and lowland rainfed systems account for more than 95 percent of rice production, so small productivity gains have a profound effect on total production. The significance of upland and deepwater rice systems lies in their contribution to food security and their impact on the environment in localities within the region.

Approximately 42 million (M) ha or 45 percent of SE Asia's cropped land is planted to rice in irrigated (18 M ha), rainfed (18 M ha), deep water (3 M ha), and upland (3 M ha) cropping systems. The largest area under irrigated rice is found in Indonesia, followed by Vietnam, the Philippines, and Thailand (**Table 2**). The largest

Table 1. A comparison of the productivity of four different rice systems.

System	Yield, t/ha	Crops/yr	Fallow period, yr	Productivity, t/ha/yr
Irrigated rice	5.0	2.5	0	12.5
Rainfed rice	2.5	1	0	2.5
Deep water rice	1.0	1	0	1.0
Upland rice[1]	1.0	1	8	0.12

[1] Grown in slash-and-burn systems, usually on sloping land.

Table 2. Area under irrigated, rainfed lowland (RLLR), upland, and other rice cropping systems in SE Asia, 1995 (IRRI Rice Facts, 2002).

Country	Irrigated	RLLR	Upland	Flood prone	Total area
	- - - - - - - -	- - - - - - - -	'000 ha	- - - - - - - -	- - - - - - - -
Cambodia	154	1,124	33	614	1,924
Indonesia	6,154	4,015	1,247	23	11,439
Laos	40	319	201	—	560
Malaysia	445	152	84	—	681
Myanmar	1,124	4,166	252	602	6,144
Philippines	2,334	1,304	120	—	3,759
Thailand	2,075	6,792	36	117	9,020
Vietnam	3,687	1,955	345	778	6,766
Total	16,015	19,827	2,318	2,134	40,293

Table 3. Estimated population, rice production, and per capita rice consumption in SE Asia.

	Year		
	2000	2020	2050
Population, millions	520	650	780
Rice production, million tonnes	150	160	180
Per capita consumption, kg	270	250	230

area under RLLR is found in Thailand, but there are also large areas in Indonesia and Myanmar. The largest area under upland rice is found in Indonesia, and significant amounts of land are planted in flood-prone areas in Cambodia, Vietnam, and Myanmar.

At present, SE Asia produces 150 M tonnes (t) of paddy per year (25 percent of world production), of which 95 percent is consumed within the region. While per capita demand is expected to decrease in the future, total demand for rice in SE Asia is expected to increase to more than 160 M t per year by 2020 due to population growth (**Table 3**).

The area under the most productive and fertile irrigated rice lands, located in areas of high population density, is expected to decrease due to the effects of rapid urbanization and industrialization. Thus, productivity in rice systems must increase from the current average of 3.4 t/ha to at least 4 t/ha if food security and export potential of SE Asia are to be maintained.

Table 4. Rice area harvested and planted to modern varieties, 1999 (IRRI Agri Facts, 2002).

	Area harvested, '000 ha	Yield, t/ha	Area planted to modern varieties	
			%	'000 ha
Cambodia	1,961	1.94	11	216
Indonesia	11,624	4.25	77	8,951
Laos	718	2.93	2	14
Malaysia	674	2.94	68[1]	458[1]
Myanmar	5,458	3.24	72	3,930
Philippines	3,978	2.95	89	4,858
Thailand	10,000	2.33	68	6,800
Vietnam	7,648	4.11	80	6,118
SE Asia	42,061	3.48	75	31,345

[1] PPI/PPIC ESEAP estimate, 2002

In Indonesia and Vietnam, where more than 50 percent of the planted area is under irrigated rice, productivity increased from 3.3 t/ha to 4.3 t/ha within one decade during the recent past. This is attributed to an expansion in the area under irrigation and the increased use of modern varieties (**Table 4**) and fertilizer nutrients (**Table 5**).

Table 5. Growth rates for rice yields, fertilizer consumption, and rice imports in SE Asia.

	Increase in rice yield, % per year		Increase in fertilizer consumption, % (1990-99)			Rice imports, '000 t		
Country	1967-90	1990-99	N	P_2O_5	K_2O	1980-89	1990-99	Change
Cambodia	0.7	2.5	22.6	3.4	0	946	472	-474
Indonesia	4.0	0	4.6	-5.4	-1.0	4,915	13,784	+8,869
Laos	4.4	2.0	26.5	15.8	10.4	157	167	+10
Malaysia	1.6	0.5	3.7	4.7	6.5	3,150	4,409	+1,259
Myanmar	2.5	0.9	12.2	11.7	-2.3	0	0	0
Philippines	3.4	-0.4	0.3	1.8	2.1	1,044	5,898	+4,854
Thailand	0.5	1.5	6.2	4.7	9.6	0	2	+2
Vietnam	2.2	2.1	15.1	16.4	37.2	2,272	28	-2,244

The national average yield in the Philippines, however, is only 3 t/ha (**Table 4**), in spite of the greater use of modern varieties and a greater proportion of total rice land under irrigation. This is partly due to smaller inputs of fertilizer nutrients (**Table 5**).

National average yields for Cambodia, Laos, Myanmar, and Thailand are also small. The main contributing factors are: 1) the lower yield

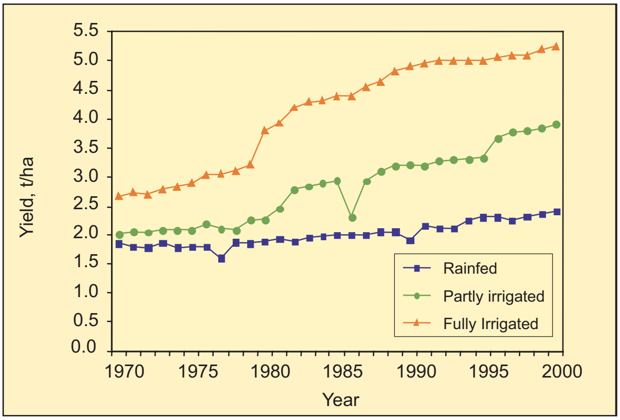


Figure 1. Rice yields in major cropping systems in SE Asia.

potential of the dominant rainfed systems, 2) greater use of traditional varieties instead of modern varieties, and 3) less efficient management of water and nutrients.

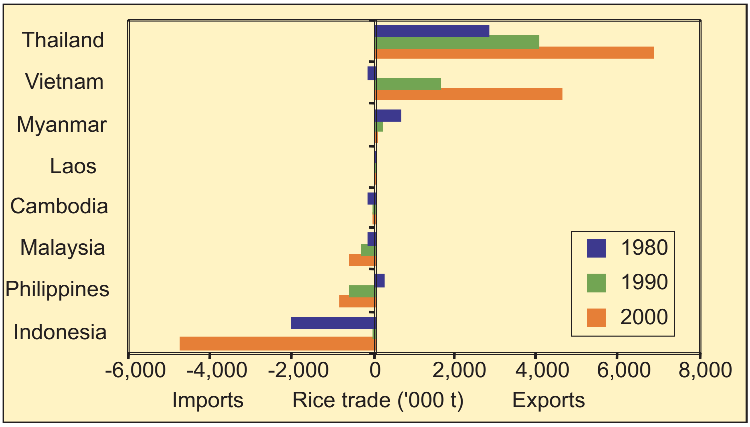
Achieving the required average yield of 4.5 t/ha in SE Asia will likely mean further increases in the area under rice, a larger proportion of rice systems under irrigation, and greater use of adapted modern varieties. Adequate nitrogen (N), phosphorus (P), and potassium (K) are also important. It is estimated that average application rates of 73 kg N/ha, 24 kg P_2O_5/ha, and 33 kg K_2O/ha will be needed to meet the levels of production required in the next 10 years.

Between 1980 and 2000, the harvested area of rice in SE Asia increased by 8.4 M ha to 43.4 M ha, the proportion irrigated increased by almost 4 M ha, and the use of modern varieties increased to 75 percent of the total area planted to rice. Impressive yield gains of up to 2 t/ha have been achieved over the period 1980–2000 in the irrigated and partly irrigated rice systems in SE Asia, but there has been little progress in the rainfed systems (**Figure 1**). There was a consistent decline in the rate of increase in rice yields compared with the 20-year period following the introduction of modern varieties in the early 1960s. During the last decade, average rice yields increased by about 1 t/ha.

Over the past three decades, Thailand has maintained its position as the region's major rice exporter (**Figure 2**). Vietnam was a rice importer in the 1980s, but began to export rice during the 1990s, and in 2000 exported more than 4 M t. Increased production in both Thailand and Vietnam is clearly correlated to the increased use of NPK fertilizers during the past 20 years.

In contrast, rice productivity growth rates in Indonesia, Malaysia, and the Philippines decreased during the 1990s, and rice imports grew to almost 6.5 M t in 2000 (**Figure 2**). Rice imports for these three countries totalled 24 M t in the period 1990–1999, an increase of about 15 M t over the total import for 1980–1989 (**Table 5**). Growth rates for the consump-

Figure 2. Trade deficits in rice in SE Asia.



tion of NPK fertilizer nutrients were small or negative in Indonesia and the Philippines during the 1990s, particularly following the economic crisis in 1997. This has further increased their dependence on rice imports.

To maintain regional self-sufficiency in rice, the irrigated and rainfed rice systems must achieve yields of 6 t/ha and 3 t/ha, respectively, over the next two decades. Major constraints to improving productivity include low soil fertility, pest and disease damage, competition from weeds, drought in rainfed systems, flooding, soil acidity, poor infrastructure, land fragmentation, and land losses due to urbanization, poor availability and high cost of inputs, low and fluctuating rice prices, land degradation due to salinization, and poor extension services. Constraints are presented in more detail in **Table 6**.

On-farm research conducted by the International Rice Research Institute (IRRI) and the National Agriculture Research and Extension Stations (NARES) on 118 farms in four SE Asia countries has shown that the improved techniques of site-specific nutrient management (SSNM) can contribute to productivity increases of 10 to 15 percent, with an average increase in net farm income of about US$50/ha/crop or US$100/ha/yr in double cropped systems. Yield and income gains were much larger, however, in well-managed farms (Dobermann et al., 2002). Successful implementation of SSNM, however, requires complementary and comprehensive crop management techniques, including pest and disease management, and the use of high quality seed. The research showed that the impact of SSNM on yield and profitability were much greater where farmers achieved high standards of general crop care. This underlines the importance of "knowledge-based" approaches to extension where farmers learn to integrate different techniques by following prescriptive and piecemeal recommendations.

The average annual fertilizer NPK consumption in rice systems of SE Asia is estimated at 4.1 M t/yr (about 100 kg/ha) or about 50 percent of total fertilizer NPK consumption in the region (**Table 7**). Nutrient consumption appears to be unbalanced with an $N:P_2O_5:K_2O$ ratio of about 8:2:1.

One consequence of unbalanced fertilizer use in the region is the extent to which the K reserves in soils are being depleted. It is estimated that at least 1 M t of K is mined each year from SE Asia's rice soils, and calculations based on research in intensified rice systems in Indonesia, Thailand, the Philippines and Vietnam show negative balances for K of 40 to 60 kg K ha/yr (Sheldick et al., 2002; Syers et al., 2001). However, when combined with improved N management techniques (i.e., more precise timing and splitting of N fertilizer, use of a leaf color chart), increased applications of K resulted in average yield increases of about 0.5 t/ha.

Table 6. Main production constraints for rice in SE Asia (modified after IRRI Rice Facts, 2002). White background indicates that a constraint exists in country indicated.

	Cambodia	Indonesia	Laos	Malaysia	Myanmar	Philippines	Thailand	Vietnam	Total*
Low soil fertility			Sandy soils			50% problem soils	>75% rice lands		5
Soil acidity							Acid sulfate soils		2
Salinity				Intrusion of seawater			NE and S coast	Coastal areas	4
Drought				Rainfed rice systems					8
Flooding	Low lying areas		Mekong River			Typhoons	In RLLR	Rainfed areas	5
Low temperatures							Upland rice in N. Irrigated in N and NE.	N Vietnam	2
Pests and diseases	Stem borer, gall midge	BPH, stem borer, BLB, blast, RTV		BPH, stem borer, blast, GLV, RTV		RTV, BLB, Blast, GLH, stem borer	BLB, blast, BPH, stem borer	BPH, stem borer, leaf roller, blast, BLB, brown spot	8
Weeds				Weeds in direct seeded rice		Direct seeded rice	Direct seeded rice	Weeds in direct seeded rice	6
Land fragmentation			Small farm size					Small farm size	3
Land security	Land mines								1
Rural poverty									2
Labour scarcity		In agriculture production areas							2
High input cost					Fertilizer				1
Input scarcity	Infrastructure, credit, seed fertilizers, agrochemicals	Lack of quality fertilizers	Infrastructure, credit, seed fertilizers, agrochemicals		Infrastructure, credit, seed fertilizers, agrochemicals			Infrastructure, credit, seed fertilizers, agrochemicals	4
Rice price policy			Low price	Low price		Price policy			5
Ineffective extension									2
Water management									2
Land loss		Urban sprawl	Erosion						2
Others		New technology required	Preference for glutinous rice		Limited market opportunity	Lack of clear policy			4
Total*	10	10	12	6	10	7	8	12	

*Total number of incidences where production constraints have been detected

Table 7. Fertilizer NPK use by rice in major agro-economics of SE Asia 2001 (PPI-PPIC ESEAP estimates, 2002).

		N		P_2O_5		K_2O		Consumption				
Country	Area '000 ha	Fertilized %	Rate kg/ha	Fertilized %	Rate kg/ha	Fertilized %	Rate kg/ha	N	P_2O_5 '000 t	K_2O	Total	Ratio
Cambodia	1,873	30	15	20	14	5	3	8.4	5.2	0.3	13.9	28.0: 17.3 :1.0
Indonesia	11,523	90	105	70	22	40	14	1,192.6	177.5	64.5	1,434.6	18.4:2.8:1.0
Laos	690	30	55	20	15	5	5	11.4	3.1	0.2	14.7	57.0:15.5:1.0
Malaysia	692	90	95	90	40	70	35	59.2	24.9	17.0	101.1	3.5:1.5:1.0
Myanmar	6,000	60	35	50	12	10	4	126.0	36.0	2.4	164.4	52.5:15.0:1.0
Philippines	4,037	85	51	85	15	75	11	175.0	51.5	33.3	259.8	5.3:1.5:1.0
Thailand	10,048	90	62	90	33	60	17	560.7	298.4	102.5	961.6	5.5:2.9:1.0
Vietnam	7,655	90	108	80	45	50	40	744.1	275.6	153.1	1,172.8	4.9:1.8:1.0
Total:	42,518							2,877.4	872.2	373.3	4,122.9	
							Ratio	8:	2:	1		

The stagnation in rice yields and the consequent increase in rice imports in Indonesia, Malaysia, and the Philippines are clearly related to the low fertilizer K application rates averaging less than 10 kg K_2O/ha in these countries. An estimated 1.3 M t K_2O/yr and 1 M t P_2O_5/yr are required to support the levels of rice productivity that will be needed to maintain self-sufficiency in the region (Greenland, 1997).

The challenge in rice systems in SE Asia is to achieve regional food security and increase farm incomes using site-specific integrated crop management techniques. This will require much greater investments in research and extension over the next two decades. **BCI**

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Rice Production and Nutrient Management in India

By K.N. Tiwari

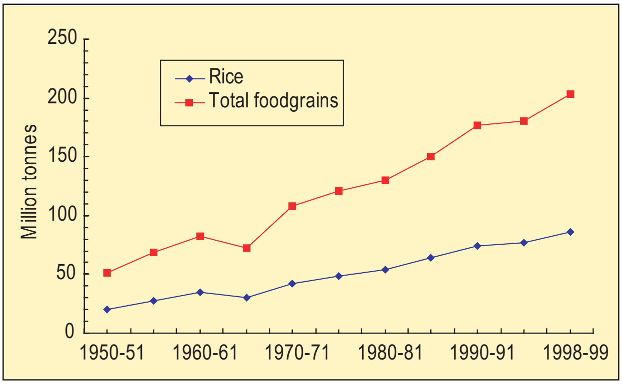
The demand for rice in India is projected at 128 million tonnes (M t) for the year 2012 and will require a production level of 3,000 kg/ha...significantly greater than the present average yield of 1,930 kg/ha. This low level of productivity can be increased substantially by growing high yielding varieties/hybrids and by increasing both the area under balanced fertilizer use and application rates.

India is the seventh largest country in the world by area, with 329 million hectares (M ha). It is also the second-most populous country (1 billion people). Demographers indicate that by 2012 India's population will reach 1.2 billion.

The net area sown is nearly 142 M ha, of which only 39 percent is irrigated, while the gross cropped area is approximately 189 M ha. There are about 106 million operational holdings with an average size of 1.57 ha. About 78 percent of the holdings are less than 2 ha, belonging to small and marginal farmers, and cover 32 percent of the total cultivated area. Despite this, the success of Indian agriculture has received worldwide appreciation as foodgrain production increased from 50.8 M t in 1950-51 to 203 M t in 1998-99.

The 189 M ha of cropped area is normally allocated accordingly: 126 M ha to foodgrain crops, including 44.6 M ha in rice, 26.0 M ha in wheat, 32.4 M ha in coarse cereals, and 23.3 M ha in pulse crops. About 63 M ha are planted to other crops. The 203 M t foodgrain production in 1998-99 was comprised of 86 M t of rice, 70.8 M t of wheat, 31.4 M t of coarse cereals, and 14.8 M t of pulses. Of the total rice area, only 51 percent is irrigated, so 49 percent is rainfed. Total foodgrain production has followed the ups and downs of rice production in India (**Figure 1**).

Figure 1. Rice versus total foodgrain production in India.



Rice continues to hold the key to sustained food security in the country, so even if rice production areas stabilize or register negative growth, future rice production targets must be achieved exclusively

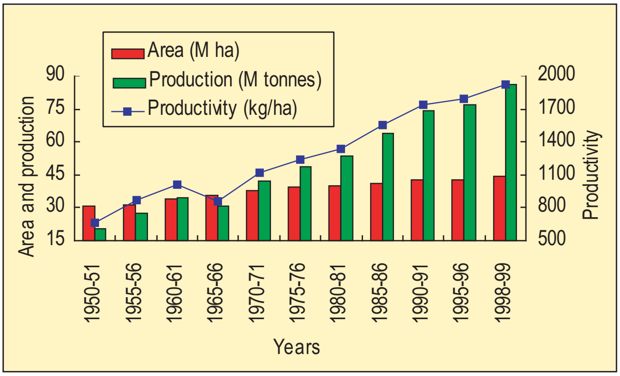


Figure 2. Area, production and productivity of rice in India.

through yield improvement. Given many under and unexploited crop production technologies, sustainable productivity can be accomplished.

Production – Productivity Growth

The state-wise area, total production, and productivity (i.e., average yield) of rice are given in **Table 1**. As shown in **Figure 2**, all three factors have changed over the past 50 years. Average rice yields vary from 1,010 kg/ha in Madhya Pradesh to 3,440 kg/ha in Tamil Nadu, with the national average being 1,930 kg/ha. Production and productivity have increased substantially from 1960 to 1990, while the area planted to rice has increased only slightly.

India is still amongst the countries with the lowest rice yields. Seventy percent of the 414 rice-growing districts report yields lower than the national average, clearly indicating that well after the advent of high yield technology, a sizable area is categorized as low producing. Sixty percent of the low productivity rice areas are in Bihar, Orissa, Assam, West Bengal, and Uttar Pradesh. Surprisingly, 32 percent of the irrigated rice areas produce low yields. Yield gap analysis further reveals that 30 to 40 percent of the potential yield is yet to be tapped with available high yielding varieties (HYV) sown on highly productive irrigated soils. This gap is likely due to degraded and less fertile soils, pockets of endemic pests and diseases, low input use, defective cropping systems, and a low adoption rate by farmers of high yielding technologies. Diagnostic and then corrective measures will substantially increase yield levels. Hence, the theory that low yields are a function of lack of irrigation (unlike in

Table 1. State-wise area, production, and yield of rice in India (1998-99).

State	Area, M ha	Percent of total area, %	Production, M t	Percent of total production, %	Yield, kg/ha
Andhra Pradesh	4.11	9.4	11.40	13.3	2,770
Assam	2.42	5.5	3.25	3.8	1,340
Bihar	5.10	11.7	6.63	7.7	1,300
Gujarat	0.62	1.4	1.02	1.2	1,640
Haryana	1.08	2.5	2.43	2.8	2,250
Jammu and Kashmir	0.27	0.6	0.59	0.7	2,180
Karnataka	1.43	3.3	3.60	4.2	2,520
Kerala	0.35	0.8	0.66	0.8	1,890
Madhya Pradesh	5.31	12.2	5.37	6.2	1,010
Maharashtra	1.48	3.4	2.47	2.9	1,670
Orissa	4.45	10.2	5.39	6.3	1,210
Punjab	2.52	5.8	7.94	9.2	3,150
Tamil Nadu	2.39	5.5	8.22	9.6	3,440
Uttar Pradesh	5.93	13.6	11.60	13.5	1,960
West Bengal	5.90	13.5	13.30	15.5	2,250
Others	1.24	1.0	2.08	2.4	1,680
All India	**44.60**	**100.0**	**86.00**	**100.0**	**1,930**

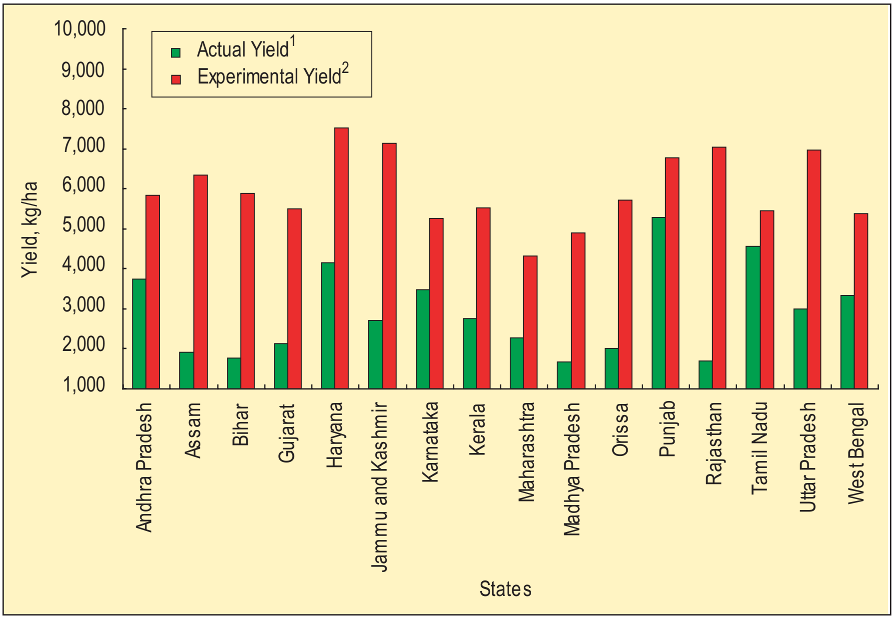


Figure 3. Yield gap between actual and experimental yields (irrigated), in India.
[1]Actual Yield=State Average Yield over Seven Year Period.
[2]Experimental Yield=Mean Yield of Best Entry at ACICRIP Test Locations over Seven Year Period.
Source: Siddiq, E.A. (2000) Survey of Indian Agriculture: The Hindu, p. 43.

China, Korea or Egypt, where over 95 percent of rice is irrigated) is not justifiable. India's yields even in irrigated fields are too low by comparison (i.e., 4.2 t paddy/ha in India compared to 6.1 and 8.3 t for China and Egypt, respectively).

Yield Gaps

Fortunately, instances of farmers harvesting yields as high as 8 to 10 t/ha occur throughout India. Rather than dismissing these as random occurrences, it would be wise to take them as pointers to what is achievable. The yield gap, derived as the percent difference between achievable (experimental) and average farmer yield in India reveals the bridgeable gap to be quite wide. With the exceptions of Tamil Nadu (15 percent) and Punjab (22 percent), it is in the range of 35 to 75 percent (**Figure 3**). If the gap itself were taken as an opportunity and research/development efforts to narrow it are given priority, the production target goal would be attainable.

To sustain the share of rice in total foodgrain production, as well as ensure sufficiency, minimum rice production and productivity required in 2006-07 are estimated as 100 M t and 2,450 kg/ha (based on a population growth at 1.9 percent and income growth at 5 percent). The production/productivity growth trend in the 1990s was one-half of realized gains in the 1980s. The zone-wise compound growth rate data given in **Table 2** indicate the range varying from 1.15 in

Table 2. Zone-wise compound growth of rice production and productivity in India.

	Annual compound growth, %		
Zone	1970-80	1980-90	1990-97
		Production	
East	0.10	6.51	1.90
North	6.81	5.03	2.11
South	2.04	2.19	1.15
West	0.69	1.42	2.34
India	1.98	3.63	1.84
		Productivity	
East	-0.02	4.06	1.97
North	-4.10	4.20	1.29
South	-0.98	2.88	0.80
West	0.41	0.96	2.12
India	-1.10	3.25	1.60

south to 2.34 in the west. Stable and high growth rates can be attributed to a) steadily increased adoption of high yielding varieties in rainfed systems, b) increased consumption of fertilizer nutrients, c) access to and timely availability of quality seed (largely facilitated through farmer to farmer spread from frontline demonstration sites), and d) adoption of production/protection practices.

Nutrient Management

Fertilizer responsive, high yielding rice varieties developed in the 1960s made it possible to produce 7.5 to 10 t of plant biomass per hectare per year. Initially, this level of production was sustained by nitrogen (N) fertilizer additions with soil and manure being the other nutrient sources. Within a few years, applying only N gradually exhausted nutrient reserves in many soils, making it impossible to produce high yields. There is now a large mass of experimental data (on-farm as well as on-station) showing that application of N, phosphorus (P), and potassium (K) fertilizers produce higher yields than either the application of N or N and P. The contribution of P and K to yield is substantial and proves that India's soils generally suffer from multi-nutrient deficiencies. Productivity, therefore, can only be sustained by planned applications of nutrients that the soil cannot provide.

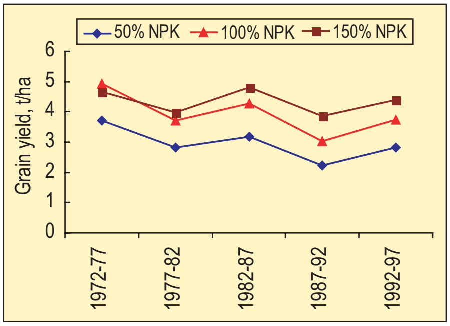


Figure 4. Long-term data (25 years) on rice yield in the alluvial zone of West Bengal with a jute-rice-wheat cropping sequence. Source: Saha et al. 1998. Long Term Fertilizer Experiments Proceedings.

Long-term fertilizer experiments clearly show a) intensive cropping with only N input is a short-lived phenomenon, b) omission of a nutrient (be it macro or micro) leads to progressive deficiency as a result of removal by the crop, c) sites initially well supplied with P, K or sulfur (S) become deficient when continuously cropped using N alone or S-free fertilizers, and d) fertilizer doses previously considered as "optimum" result in soil nutrient depletion because of high productivity levels.

As an example, data from a jute-rice-wheat cropping sequence in an alluvial soil from West Bengal (**Figure 4**) indicate the present state-recommended dose of NPK was inadequate to sustain optimum yields in an intensive cropping system. The results of long-term fertilizer experiments conducted with rice-based cropping system at several stations confirm the inadequate nature of so-called 'optimum' fertilizer recommendations (**Table 3**). Results of hybrid rice experiments conducted at C.S. Azad University of Agriculture and Technology, Kanpur, taking into consideration all

Table 3. Sub-optimal status of optimum fertilizer recommendations, India.

	Mean rice grain yield (1972-96), t/ha		
Location	Optimum NPK	1.5 x Optimum	Extra yield, %
Barrackpore	4.0	4.4	+11
Bhubaneswar	3.0	3.3	+11
Hyderabad	3.6	4.3	+19

Source: Swarup, A. (1998), Long Term Fertilizer Experiments Proceedings.

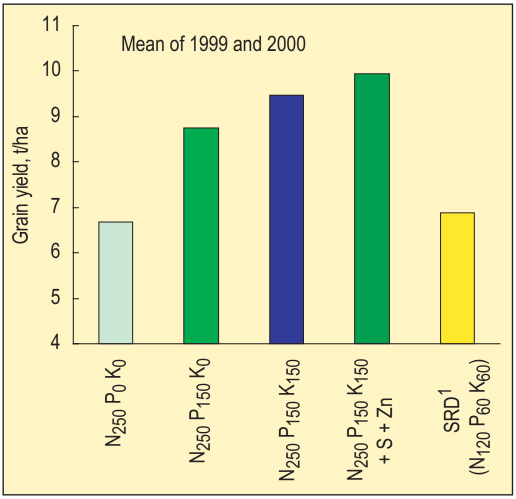


Figure 5. Effect of balanced fertilization on grain yield (paddy) of hybrid rice in Gangetic alluvium of Uttar Pradesh. Source: Pathak, R.K. 2000. Annual Report PPIC–IP Sponsored Research Project. [1]State recommended fertilizer dose (N_{120} P_{60} K_{60}).

nutrient deficiencies, reveal that yields of nearly 10 t/ha can be obtained through site-specific nutrient management involving the use of 250-150-150-40-5 kg N-P_2O_5-K_2O-S-zinc (Zn)/ha. The yield obtained with the state recommended fertilizer dose ($N_{120}P_{60}K_{60}$) was only 6.87 t/ha (**Figure 5**).

From these various research and demonstration trials, it can be concluded that: (a) efficient nutrient management in high yielding rice varieties/hybrids substantially increases the crop's productivity and (b) the current general use of P and K is very low and to the point where P and K requirements by rice exceed total fertilizer consumption. To achieve rice production targets by 2012, balanced and adequate use of P and K fertilizers as well as N, S, and Zn is essential.

Yield plateauing in irrigated areas has necessitated turning the focus to rainfed rice ecology. Improved rice production and productivity in rainfed areas may not only help the resource-poor farmers, but also substantially increase food production. Eastern India is the major rice-growing region of the country. It accounts for about 63 percent of the total rice-cropped area, but produces only 48 percent of the total yield.

About 80 percent of the rice area of eastern India is rainfed and exposed to abiotic stresses such as drought, low soil fertility, flood, and stagnant water. Farmers do not want to spend scarce resources on fertilizers and generally apply only N fertilizers. Thus, yields are constrained by poor soil fertility, leading to nutrient deficiencies and low income for farmers.

It has now been well established that rice in rainfed areas responds well to P and K applications which provide drought and disease-pest resistance to the crop. In fact, even in rainfed areas, extensive over-exploitation of soil nutrient reserves has already occurred. Therefore, to increase productivity under rainfed conditions, balanced fertilization would be essential and inevitable. There is urgent need to educate farmers about the importance of balanced use of fertilizers in increasing yields and profits in rainfed rice ecology. **BCI**

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Nutrient Deficiency Symptoms in Rice

Symptoms of nutrient deficiency or toxicity are not always readily apparent in a growing crop. Often, more than one nutrient or growing condition may be involved. In many field situations, when a deficiency is identified, it may be too late for treatment to correct the problem in the current crop.

The following pages present some photos and brief information describing symptoms of nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn) deficiencies in rice. More comprehensive information on these and other nutrients is available from various other sources, including the handbook, *Rice: Nutrient Disorders & Nutrient Management*, described on page 47.

Nitrogen

Nitrogen deficiency is the most commonly detected nutrient disorder observed in rice. Old leaves and sometimes all leaves become light green and chlorotic at the tip. Leaves die under severe stress. Except for young leaves, which are greener, deficient leaves are narrow, short, erect, and lemon-yellowish. The entire field may appear yellowish. Nitrogen deficiency often occurs at critical growth stages such as tillering and panicle initiation, when the demand for N is large.

Leaves are yellowish-green in the omission plot where N has not been applied.

Leaves are smaller in N-deficient plants.

Tillering is reduced where N is deficient.

Greater tillering occurs where N fertilizer has been applied.

Growth may be greatly reduced by Zn deficiency (at left in photo).

Zinc deficiency results in stunting and uneven plant growth, as shown in foreground.

Zinc

Zinc deficiency symptoms are more common on young or middle-aged leaves. Dusty brown spots appear on upper leaves of stunted plants, sometimes two to four weeks after transplanting, with uneven plant growth and patches of poorly established hills. Under severe deficiency, tillering decreases and time to crop maturity may be increased.

Phosphorus

Stunted, dark green plants with erect leaves and reduced tillering may signal P deficiency. Leaves are narrow, short, very erect, and 'dirty' dark green. Stems are thin and spindly, and plant development is retarded. The number of leaves, panicles, and grains per panicle may also be reduced. Young leaves may appear to be healthy, but older leaves turn brown and die. Red and purple colors may develop in leaves if the variety has a tendency to produce anthocyanin. Leaves appear pale green when N and P deficiency occur simultaneously.

Phosphorus is particularly important in early growth stages. It is mobile within the plant and promotes root development, tillering, early flowering, and ripening (especially where the temperature is low). Addition of mineral P fertilizer is required when the rice plant's root system is not yet fully developed and the native soil P supply is small. Phosphorus is remobilized within the plant during later growth stages if sufficient P has been absorbed during early growth.

Phosphorus-deficient plants are stunted and small.

Tillering is reduced where P is deficient. Even under less pronounced P deficiency, stems are thin and spindly, and plant development is retarded.

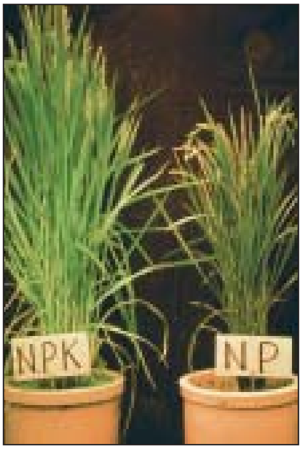
Leaf margins become yellowish-brown when K is deficient. Dark brown spots appear on the leaf surface. Leaf bronzing is also a characteristic of K deficiency.

Potassium deficiency symptoms are more likely to occur in hybrid rice (at left in photo) than in modern inbred varieties (right).

Potassium

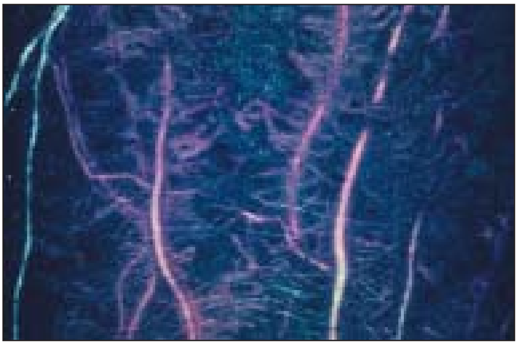
While K does not have a pronounced effect on tillering, it does affect the number of spikelets per panicle, percentage of filled grains, and grain weight. Potassium improves the rice plant's tolerance of adverse climatic conditions, lodging, insect pests, and diseases. Deficiency symptoms tend to occur in older leaves first, because K is very mobile within the plant and is translocated to young leaves from old senescing leaves. Often, yield response to K fertilizer is observed only when the supplies of other nutrients, especially N and P, are sufficient.

Dark green plants with yellowish brown leaf margins or dark brown necrotic spots first appear on the tips of older leaves. Under severe K deficiency, leaf tips are yellowish brown. Symptoms appear first on older leaves, then along the leaf edge, and finally on the leaf base. Upper leaves are short, droopy, and "dirty" dark green. Older leaves change from yellow to brown and, if the deficiency is not corrected, discoloration gradually appears on younger leaves. Leaf symptoms of K deficiency are similar to those of tungro virus disease. Unlike K deficiency, however, tungro occurs as patches within a field, affecting single hills rather than the whole field. **BCI**



Rice yields are often constrained by unbalanced fertilization where the response to N and P is constrained by insufficient K.

Potassium-deficient rice plant roots may be covered with black iron sulfide (photo at left), compared with healthy rice roots which are covered with red-brown iron oxide (photo at right).



Rice Production and Fertilization in China

By Ji-yun Jin, Ronggui Wu, and Rongle Liu

Cooperative field research during the last two decades has quantified the contribution of balanced fertilization practices for rice in China. Despite large improvements in yield and quality, it is clear that great potential still exists.

Rice is a major grain crop grown in China…the country is the world's leader in rice production. The area sown to rice in 1999 was 31.3 million hectares (M ha). This land accounts for 28 percent of China's total grain crop area and 39 percent of the country's total grain production (**Table 1**).

The area sown to rice has been relatively stable since 1980. However, total paddy production has increased from 139 million tonnes (M t) in 1980 to 198 M t in 1999 (42 percent increase). The yield per hectare increased from 4,120 kg in 1980 to 6,345 kg in 1999 (54 percent increase), contributing greatly to the increase in total grain production in China.

Many factors have contributed to this stable increase of rice yield and production during the last 20 years. Increased fertilizer input and improvements in fertilization technology are considered as keys to this success. From 1980 to 1999, total inorganic fertilizer consumption in China increased from 12.7 to 41.3 M nutrient tonnes. Considering a total arable land area of 133.3 M ha with a multi-cropping index of 156 percent (total sown area is 208 M ha), the average plant nutrient application rate from inorganic fertilizer in 1999 was estimated as 198 kg/ha.

There is no official information available in terms of fertilizer use by crops in China. In 1996, the Soil and Fertilizer Institute of the Chinese Academy of Agricultural Sciences conducted a fertilizer use survey among nearly 2,000 farmers in seven representative provinces. Most cropping systems were represented, including those involved in rice production. The survey indicated that farmers paid good attention to fertilizer

Table 1. Rice production in China from 1980 to 1999.

	1980	1985	1990	1995	1999
Sown area, M ha	33.8	32.1	33.1	30.7	31.3
Percent of grain crop area	29.0	29.5	29.1	27.9	27.7
Production, M t	139.0	169.0	192.0	185.2	198.0
Percent of grain production	43.8	44.5	42.3	39.7	39.0
Yield, kg/ha	4,120	5,250	5,800	6,020	6,340

Source: China Agriculture Year Books.

Table 2. Average rice yields and fertilizer rates in selected provinces in 1995.

Province	Rice type	N	P_2O_5	K_2O	Total	$N:P_2O_5:K_2O$ ratio	Yield, kg/ha
		kg/ha					
Guangxi	Early	200	51	119	366	1.7:0.4:1	6,300
	Late	179	46	110	329	1.6:0.4:1	4,720
Hubei	Early	157	50	45	232	3.5:1.1:1	5,290
	Late	160	48	54	232	3.0:0.9:1	6,030
	Mid	178	59	61	263	2.9:1.0:1	6,930
Jiangsu	Mid	274	68	56	348	4.9:1.2:1	7,640
Jilin	Mid	217	69	66	315	3.3:1.0:1	8,560
Shaanxi	Mid	227	67	69	278	3.3:1.0:1	7,860
Shandong	Mid	215	58	66	335	3.2:0.9:1	7,050
Sichuan	Mid	152	63	61	211	2.5:1.0:1	7,530
Average		196	58	71	291	2.8:0.8:1	6,790

Source: Liu Rongle, 2001.

use in rice production. The mean weighted average use of plant nutrients by the surveyed farmers was 291 kg/ha for their rice production, which is significantly higher than the 198 kg/ha of plant nutrients for the country average (**Table 2**).

Nitrogen (N) fertilization rates were found to vary greatly from province to province, ranging from 152 kg/ha in Sichuan to 274 kg/ha in Jiangsu, the surveyed province with the most developed rural economy. A relatively small variation in terms of phosphorus (P) application rates was found among the provinces and rice types, with average P_2O_5 rates ranging between 46 to 69 kg/ha. As for potassium (K), farmers in Guangxi used more K than other provinces, probably due to low soil K levels and the effect of a longer history of good K-promoting educational activities targeted at farmers in this region. Guangxi was where the Canpotex balanced fertilizer demonstration program was initiated. It was successful in showing large numbers of farmers, government officials, and others the benefits of including appropriate rates of K in a balanced fertilizer crop production system.

The $N:P_2O_5:K_2O$ ratios varied widely, in the range of 1.6-4.9:0.4-1.2:1 among the various provinces and rice systems. The average ratio was 2.8:0.8:1, although the ratios recommended by the local agricultural technicians were in the range of 1.2-2.5:0.3-0.6:1. This indicates significant opportunities for further improving balanced fertilization in rice, especially by increasing P and K use to increase yields and quality (**Table 2**).

Rice growth response to K is shown in plot at left, compared to no-K plot at right, in Heilongjiang.

To improve agricultural production through balanced fertilization technology, the PPI/PPIC China Program began cooperative research and educational activities with Chinese institutions through coordination by the Ministry of Agriculture (MoA) and financed jointly by Canpotex and the Canadian International Development Agency (CIDA). Initiated in 1982 in two southern provinces, this cooperative effort expanded to all mainland provinces and covers more than 40 different crops, including rice-based cropping systems in both the southern and northern regions of China.

In the 1980s, a total of 1,858 field

trials on balanced fertilization on rice were conducted and results summarized. An average 11.5 percent yield increase was achieved by applying 50 to 90 kg K_2O/ha to the traditional N and P rates used by farmers. Average yields in the NP treatment ranged from 4,500 kg/ha to 6,500 kg/ha, meaning that one kg K_2O increased paddy yield by 5 to 10 kg.

By the early to mid 1990s, rice yields had generally increased, the result of improved varieties and other management practices. At the same time, it was recognized that the agronomic requirement for balance among fertilizer nutrients demanded increased rates of P and K to assure high rice yields of good quality.

Results of the PPI/PPIC China Program cooperative fertilization trials on rice are summarized in **Table 3**. Average of best yields achieved with all plant nutrients balanced and the corresponding N, P_2O_5, and K_2O fertilizer rates and ratios, as well as average net benefit of K fertilizer use, are noted.

Results clearly indicated that overall rice production and farmer income were significantly improved by balanced fertilization. The average best yields achieved with balanced NPK fertilization for rice grown in southern China, regardless of planting season, increased substantially. Omitting K (NP treatment) from the balanced fertilization treatment resulted in significant paddy yield reductions of 13, 22, and 9 percent for early, late, and middle rice, respectively. Average paddy yield of all trials (including early, late, and middle season rice) with the best treatments was 8,150 kg/ha, with a 13.3 percent yield reduction if K was not used. The average net benefit from K application ranged from 459 Chinese yuan (RMB) per hectare for middle season rice to 1,690 RMB/ha for late season rice (8.2 yuan = US$1).

To achieve high yield rice production, rational input of inorganic fertilizers is a key management practice. The weighted mean of N,

Table 3. Rice yield responses to balanced fertilization in the 1990s in China.

Region	Rice type	Fertilizer use, kg/ha $N\text{-}P_2O_5\text{-}K_2O$	$N:P_2O_5:K_2O$	Paddy yield, kg/ha NP	NPK	Yield increase %	kg paddy/kg K_2O	Net benefit RMB/ha[2]
South China	Early (32)[1]	142-57-161	0.9 : 0.4 : 1	6,610	7,500	13.3	5.1	569
	Late (23)	188-66-198	0.9 : 0.3 : 1	8,230	9,970	21.7	8.7	1,690
	Mid (42)	194-96-171	1.1 : 0.6 : 1	7,070	7,650	8.8	3.3	459
	Mean (97)	176-76-174	1.0 : 0.4 : 1	7,197	8,150	13.3	5.2	796
North China	Rice (16)	202-112-127	1.6 : 0.9 : 1	6,700	7,801	16.3	10.7	1,515
	Grand mean (113)	179-81-168	1.1 : 0.5 : 1	7,130	8,102	13.8	5.9	1,030

[1] Numbers in parentheses indicate the number of trials conducted.

[2] Average prices of early, late, and middle rice from the south and rice from the north were 1.0, 1.2, 1.4, and 1.6 RMB/kg, respectively; cost of K_2O was 2.0 RMB/kg.

Source: PPI/PPIC China Program.

P_2O_5, and K_2O rates in the best treatments from southern China were 176, 76, and 174 kg/ha, respectively. With a ratio of 1.0:0.4:1 (**Table 3**), these rates were much more balanced than farmer practice (survey data), with a ratio of 2.8:0.8:1 (**Table 2**). As a result of rational rates and balanced use of inorganic fertilizers, yield and farmer profit were remarkably improved (**Table 3**).

In demonstration plots in Liaoning, rice with balanced fertilization (at right) showed superior growth compared to usual farmer practice (at left).

Balanced fertilization field research on rice in northern China did not begin until the early 1990s. Results show that an average best yield of 7,800 kg/ha using soil test-based balanced fertilization recommendations required 202 kg/ha N, 112 kg/ha P_2O_5 and 127 kg/ha K_2O, giving a ratio of 1.6:0.9:1 (**Table 3**). Omitting K from the balanced fertilization treatment resulted in a 16 percent yield reduction. Stated another way, one kg of K_2O produced 10.7 kg of paddy grain. The average net benefit from K application in the north was 1,515 RMB/ha.

The approach taken by PPI/PPIC in developing the balanced fertilization technology was to use soil testing as a basis for identifying all plant nutrient deficiencies and assuring these nutrients were applied. Since this is a site-specific technology, it must be made clear that fertilization practices at the different sites reported in these discussions were not equal.

As well, secondary and micronutrients were applied as needed. It is important to note that it is highly unlikely that the magnitude of yields obtained would have been achieved had these additional plant nutrients not been applied. Unpublished data in reports of field trials at the various sites support this statement.

In summary, it is clear that great potential remains to further increase rice production in China through adoption of improved fertilization techniques. If the research evidence had been implemented and 10 percent higher yield levels achieved, in 1999 China would have produced an extra 20 M t of rice (a production value of 28 billion RMB). Current PPI/PPIC China Program activities are highlighting the transfer of fertilizer technology to farmers since it is obvious this message has not been received on a widespread basis. **BCI**

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Rice Production in the United States – An Overview

By C.S. Snyder and N.A. Slaton

The combined effects of higher-yielding varieties, better fertility management, threshold-based pest management, and intensive irrigation management have enabled rice producers in the United States (U.S.) to continuously increase national average rice yields since the early 1980s.

Rice is the staple food of more than one-half of the world's population. Archeologists suggest that rice cultivation began in China more than 5,000 years ago. Rice culture in the U.S. began in the Carolinas and Georgia about 300 years ago and is one of the nation's oldest agri-businesses. After the Civil War, cultivation shifted westward to the lowlands of Louisiana and Texas.

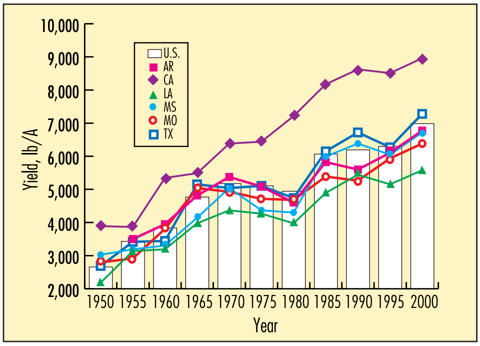
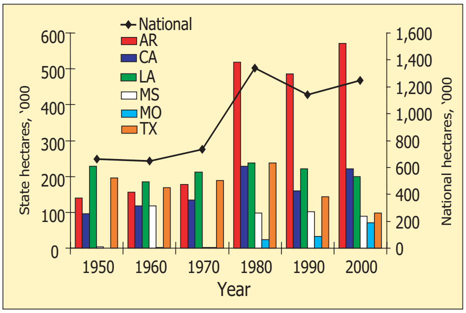


Figure 1. U.S. national and state average rice yields–1950 to current. Source: USDA-NASS.

Figure 2. State and U.S. national rice hectarage harvested –selected years. Source: USDA-NASS.



Modern rice production in the U.S. is concentrated in Arkansas, California, Louisiana, Mississippi, Missouri, and Texas, using different cultural production practices. The first U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) records for rice indicate 118,300 hectares (ha) were harvested in 1895 with an average yield of 1,280 kg/ha. Harvested area increased to more than 0.41 million (M) ha in 1919, 0.81 M ha in 1959, and 1.22 M ha in 1980. The greatest harvested area to date was 1.5 M ha in 1981, with an average yield of 5,400 kg/ha.

State and national rice yields are shown in **Figure 1**, for 1950 and every five years since. The highest national average yield was reported in 2000 at 6,990 kg/ha for 1.25 M ha. Seventy-three percent of the rice hectarage grown in 2000 was long grain, 26 percent was medium grain, and about one percent was short grain rice. California has the highest average yields (**Figure 1**), while Arkansas has the greatest hectarage (**Figure 2**). In general, a single crop is harvested from most U.S. rice fields each year. In Texas and southwest Louisiana, a second or ratoon crop may be harvested from a single planting because of the longer growing season.

U.S. rice hectarage has shifted from year to

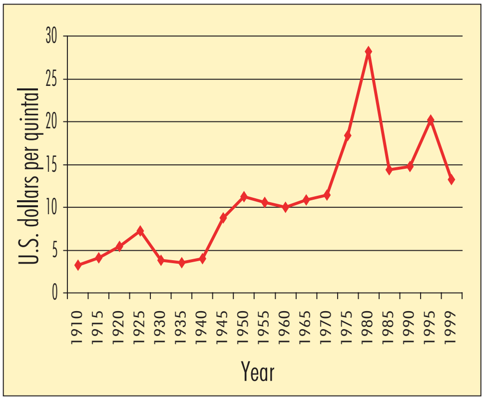


Figure 3. Average U.S. rice price. Source: USDA-NASS.

year depending on many factors: marketing quotas, government hectarage allotments, export demand, production deficiency payments, hectarage reduction programs, water availability, and the government "freedom-to-farm" policy. Production costs vary among the rice producing states and are influenced by factors such as seeding method, soil type, and variety-dependent nitrogen (N) rate. Average U.S. price per quintal ranged from US\$4.40 in the early 1920s to a high of over US\$28.22 in 1980. It is currently around US\$13.22 (**Figure 3**). Total direct production costs (excluding fixed expenses: tractors, implements, self-propelled equipment, and irrigation systems) have ranged from about US\$716 to US\$958/ha/year. Fertilizer costs have ranged from about US\$109/ha for N-only programs to US\$163/ha for N, phosphorus (P), potassium (K), sulfur (S), and zinc (Zn) programs in the Midsouth, to US\$212 for N and P programs in California. Fertilization costs account for about 13 to 26 percent of the annual direct production costs.

Fertilization

Nitrogen is the fertilizer nutrient required in the greatest amount for maximizing rice yields. Fertilizer N use efficiency (NUE) is usually greatest in dry-seeded production systems when it is applied to dry soil, just prior to permanent flood establishment. Urea is the most common N source because of its high analysis and relatively low cost per kilogram of N. Only ammonium-N (NH_4-N) fertilizer sources are recommended because the NH_4 is stable under flooded soil conditions. Nitrate-N (NO_3-N) sources are subject to denitrification losses after flooding and are not recommended for use. Nitrogen is often applied up to three times during the season: approximately 50 to 70 percent of the total N rate at pre-flood, 15 to 25 percent at 1.25 cm internode elongation (IE), and 15 to 25 percent at 10 to 14 days after 1.25 cm IE. Isotopic N studies have shown that plant recovery of urea-N fertilizer can approach 70 to 75 percent when applied in a three-way split.

Grain yield and NUE are reduced when: flood establishment is delayed after the pre-flood fertilizer N application; fertilizer N is applied to a wet soil; and/or N fertilizer is applied into the floodwater for seedling rice uptake. The goal with the pre-flood application is to incorporate fertilizer N into the soil with the floodwater. This positions N in the root zone, below the oxygenated soil-water interface, limiting nitrification and the potential for subsequent denitrification. According to research and monitoring of water quality in Texas and Arkansas, N and P concentrations in surface runoff from flooded commercial rice fields are frequently lower than groundwater pumped onto the fields. The rapid nutrient uptake and filtering effects of rice make runoff N and P losses negligible under recommended fertilizer and irrigation management practices.

The appropriate agronomic N rates and best times of application are determined by each state based on variety and cultural management-specific research. Prior to 1995, a three-way split application of N fertilizer was common in the Midsouth. A two-way split (pre-flood and at IE) has recently replaced the three-way split in the Midsouth states because of more precise irrigation management and increased planting of short-season, stiff-strawed cultivars.

Recent legislation in California is phasing out the common practice of rice straw burning. Therefore, straw must be incorporated or removed from fields. Many rice farmers in California and the Midsouth re-flood fields in the winter months to create a more favorable habitat for waterfowl. The impact of these practices on nutrient cycling...especially N, carbon (C), and K...and how to manage both pre-plant and post-plant nutrients is currently being studied.

Research suggests that maximum rice yields can be obtained using less total seasonal fertilizer N when the majority of N is applied immediately before flooding during vegetative growth. Thus, recommendations are shifting towards the use of a single, large pre-flood N rate with fertilizer NUE monitored at midseason growth stages. Where it is difficult to establish or maintain a permanent flood in a timely manner, many farmers continue to use a two-way split: 65 to 135 kg N/ha (depending on variety) pre-flood with the remainder (about 65 kg N/ha) applied at midseason, beginning at IE to 1.25 cm IE. The N rate on clay soils is generally 20 to 35 kg N/ha greater than those recommended for silt loam soils.

The need for a midseason N application in the Midsouth is increasingly being based on plant biomass estimates of total N uptake using a plant area reference board, calibrated and specific for the variety and growing degree unit [DD-10 (°C)] accumulation. The DD-10 program is used extensively in Arkansas and some adjacent states to assist growers in making up to 26 management decisions. In Texas and some other areas, midseason N requirements are sometimes based on chlorophyll meter readings from recently matured leaves. In California and other states, laboratory N analysis of sampled flag leaf or Y-leaf tissue determines the need for midseason N. Midseason fertilizer applications are typically made by airplane or helicopter.

In water-seeded, permanently flooded systems, the maximum response to N is achieved by NH_4-N pre-plant incorporated 5 to 10 cm deep into a dry seedbed before flooding. Additional N is applied at midseason as needed. In an effort to reduce weed pressure from red rice, water-seeded systems are sometimes used, especially in Louisiana. It is usually beneficial to broadcast some of the N during the pin-point drain (after water seeding to ensure anchoring of roots) and prior to re-flooding.

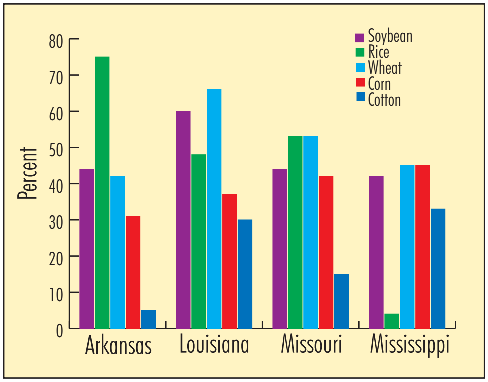
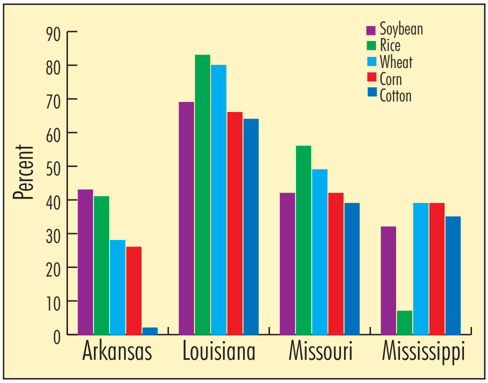


Figure 4. Crop hectarage (percent) with medium or lower soil test P in selected states, 1995-96.

Balanced fertilization with P, K, S, and Zn in many rice fields is essential for production of high yielding rice and to attain maximum NUE. These nutrients are usually applied to silt and sandy loam soils based on soil test recommendations. Rice farmers commonly use 35 to 65 kg P_2O_5/ha, 65 to 100 kg K_2O/ha, and from 10 to 20 kg S/ha. Although infrequent, silty clay and clay soils may also receive P, K, and S fertilizers. Zinc is often applied on many alkaline silt loam soils (pH >7.0) and occasionally to clays at rates from 1 to 11 kg Zn/ha, depending on the Zn source and time/method of application. Deficiencies of any of these nutrients can reduce plant growth, encourage disease development, interfere with normal plant maturity, and limit yield.

Historically, P and K fertilizers were seldom applied directly to rice. Rice relied on residual P and K from fertilizer applied directly to other crops in the rotation. Early research indicated that rice yield responses to P fertilization were infrequent because P was released from iron (Fe) and aluminum (Al) compounds in the soil upon flooding. However, many rice fields now have a long history of irrigation with well water (groundwater), and significant amounts of calcium bicarbonate have been deposited. Soil pH has risen to the alkaline range, and forms of soil P have shifted to include calcium phosphates, which are not as affected by reduction upon flooding.

Figure 5. Crop hectarage (percent) with medium or lower soil test K in selected states, 1995-96.



Recent research suggests that economic rice yield responses to P fertilization are most likely to occur on alkaline soils or where land-forming has removed topsoil. Soil test summaries from several Midsouth states reveal that soils used for rice production generally have some of the lowest P and K soil test levels compared to those used for the production of other major field crops (**Figures 4 and 5**). Most of the soils used for rice production in Texas and Mississippi are acid to strongly alkaline silty clays and clays that do not test as low in P and K as the silt loam soils in other states. Soil test P levels for these clayey soils in Mississippi and Texas range from low to high, and K levels often test in the high range. In Arkansas, the responses to recommended rates of P have ranged from 500 to 2,500 kg/ha on alkaline silt loams testing medium or lower in Mehlich 3 P (less than 15 to 25 parts per million [ppm]). Responses to K typically range from 500 to 1,500 kg/ha on soils testing medium or lower in Mehlich 3 K (less than 90 ppm). In response to the increased frequency of P and K deficiencies in rice, university research efforts and industry and extension educational programs concerning crop nutritional requirements have intensified. More Midsouth farmers have begun to apply maintenance rates of P and K to silt loam soils, equivalent to the rate of harvest removal (0.64 kg P_2O_5 and 0.40 kg K_2O/quintal). Failure to increase or at least maintain soil test P and K levels on soils used for rice production has been blamed for compromising Midsouth soil fertility management and lowering the yield potential of rotational crops such as wheat, soybeans, corn, and grain sorghum.

Land Preparation, Planting, and Irrigation

The majority of U.S. rice has typically been planted with grain drills on prepared seedbeds following several tillage and smoothing operations. Seed are usually drilled at about 430 seed/m^2 under ideal conditions, to provide a uniform stand of about 160 to 215 plants/m^2. Adjustments from the standard seeding rate are made for different varieties, tillage systems, seeding methods, and environmental conditions.

Many fields are shaped to a uniform grade to facilitate efficient flood irrigation and field drainage prior to harvest. Either before or after planting, levee (soil burm) locations are laser surveyed and marked. After planting in dry-seeded systems, levees are established at 3- to 6-cm elevation intervals using levee discs or squeezers. The levees are established on the contour, except where precision leveling has been conducted to facilitate straight levees. Rice seeds are usually broadcast on the levees, from the tractor, and incorporated during the last trip(s) over the levee in the forming process.

Levee gates, or spills, are established in each levee using metal and/or vinyl frames, to permit maintenance of a shallow 5- to 10-cm flood depth in each paddy throughout the growing season. Desirable irrigation pumping capacities from wells, surface reservoirs and streams enable farmers to flush water across an entire field (15 to 65 ha) in three to four days and to flood a field in three to five days. Precise flood irrigation management is one of the most important factors affecting NUE and integrated pest management practices. Irrigation is stopped, and fields are drained about 14 and 25 days after heading, respectively.

Pest Management

Field scouting is used to detect weed, disease, and insect infestations and to time pest management control practices. Plant protectants are applied in-season according to research-based treatment thresholds

Photo courtesy of Alan Williams.

Rice harvest near Jonesboro, Arkansas.

in integrated pest management programs. Plant nutritional status, as affected by nutrient management, may impact rice response to pests and pest management strategies. The relative level of soil fertility most dramatically affects disease reaction. Inadequate or excessive fertilization, especially with N, may increase the frequency and severity of many rice diseases. Ensuring adequate K nutrition has reduced the incidence of brown leaf spot, stem rot, and some other diseases. Sheath blight (*Rhizoctonia solani*), blast (*Pyricularia oryzae*), straighthead (physiological disorder), stem rot (*Sclerotium oryzae*), kernel smut (*Neovossia barclayana*), black sheath rot (*Gaeumannomyces graminis* var. *graminis*), brown leaf spot (*Bipolaris oryzae*), scab (*Fusarium graninearum*), Fusarium sheath rot (*Fusarium proliferatum*), and other diseases are managed/controlled through appropriate selection of tolerant/resistant varieties, balanced fertilization, rice stubble management, and rotation to non-host crops.

Summary

Rice grower support of public breeding and management research programs has led to the release of high-yielding short-statured and semi-dwarf varieties. The combined effects of higher-yielding varieties, better fertility management, threshold-based pest management, and intensive irrigation management have enabled U.S. rice producers to continuously increase the national average rice yields since the early 1980s (**Figure 1**). The adoption and use of site-specific management technologies…such as global positioning system (GPS)-referenced yield monitoring, variable rate or management-zone application of nutrients and soil amendments, remote sensing, etc…is increasing, especially where significant precision land leveling has been performed to improve irrigation water use efficiency. The trend toward improved management and higher U.S. rice yields is likely to continue as the world demand for rice grows. **BCI**

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Rice Nutrition Management in Latin America

By José Espinosa

Rice production in Latin America has both social and economic relevance. It generates significant employment and contributes greatly to the gross national product of countries in the region. High yields are important as rice is a staple food in the Dominican Republic, Guyana, Panama, Peru, and Suriname. It is an important and common food in Brazil, Colombia, Haiti, Cuba, Ecuador, Venezuela, Nicaragua, and other countries in the region.

Total rice production is affected by planted area and yield per hectare. Changes in planted area are mainly the result of governmental policies. Total harvested area in Latin America decreased between 1980 and the mid 1990s, largely due to less upland rice production in Brazil. However, a significant increase is apparent in several countries, including Argentina, Uruguay, Peru, and Ecuador (**Table 1**). Latin America still has appreciable land and water resources available to expand rice production, especially in Brazil, Colombia, and Venezuela. To date, area expansion has not been necessary because of the increasing production per hectare resulting from the adoption of high yielding varieties and improved crop management practices.

Rice growing areas of Latin America, both upland (47 percent) and irrigated (53 percent), are located on alluvial land, river estuaries, deep valleys, and flat land. Rice is cultivated under several climatic conditions that range from dry to very wet. Soil conditions also vary with climate and parent material. Mollisols, Vertisols, and Inceptisols in the drier areas have high pH and good fertility, whereas Inceptisols, Ultisols and Oxisols in the wetter areas have low pH and medium to low fertility. The latter are savanna soils located in Brazil, Colombia, and Venezuela, the area considered most important for future expansion in rice production.

Rice Fertilization and Soil Management

Commercial quality, high yields are possible using semi-dwarf varieties with high tillering potential. These varieties have a high nutrient demand, particularly for nitrogen (N). The nutrient demand for high yielding rice is partially met by the soil, but supplemental fertilizer is required during rapid growth stages when nutrients are in greatest demand. Nutrient management, along with pest, disease, and weed

Table 1. Total land area under rice and average production in Latin American countries.

	Area, '000 ha				Yield, t/ha		
Country	1990	1995	2000		1990	1995	2000
Argentina	117.0	184.0	190.0		3.67	5.03	5.01
Bolivia	109.0	130.0	170.0		1.93	2.03	2.05
Brazil	3,950.0	4,380.0	3,630.0		1.88	2.57	3.01
Chile	32.6	33.9	27.0		4.17	4.30	4.19
Colombia	521.0	407.0	440.0		4.06	4.28	4.77
Costa Rica	61.0	48.3	80.0		3.44	3.69	3.28
Cuba	155.0	87.0	123.0		3.06	2.56	2.28
Ecuador	269.0	396.0	366.0		3.12	3.26	3.59
El Salvador	14.3	9.6	14.0		4.33	5.33	4.31
Guatemala	14.3	11.0	15.0		3.11	2.79	2.57
Guyana	51.4	127.0	145.0		3.03	3.97	4.14
Honduras	17.6	13.2	5.7		2.50	2.61	1.27
Mexico	105.0	78.4	97.9		3.74	4.68	4.60
Nicaragua	45.9	62.7	80.2		2.63	3.71	3.56
Panama	98.4	99.0	150.0		2.26	1.78	2.37
Paraguay	34.0	48.0	25.0		2.52	2.84	3.72
Peru	185.0	203.0	300.0		5.23	5.62	5.55
Dominican Rep.	89.4	102.0	120.0		4.79	4.77	4.43
Suriname	52.0	60.0	50.0		3.77	4.03	3.61
Uruguay	78.1	146.0	205.0		4.45	5.50	5.73
Venezuela	115.0	177.0	150.0		4.31	4.27	4.91
Total	**6,100**	**6,800**	**6,380**	**Average**	**3.43**	**3.79**	**3.76**

control, is a common management practice that increases nutrient use-efficiency and allows production of economic yields.

Nutrient removal varies with crop variety. Knowledge of the amount and dynamics of nutrient removal is necessary to design fertilizer recommendations and timing of application. An example of nutrient removal data for cv. *CR-1821*, a variety from Costa Rica that produces high yields and has a high nutrient demand, is presented in **Figure 1**. Tested under semi-commercial conditions and irrigation, it produced a total dry matter yield of 20.3 t/ha: 9.3 t/ha of grain and 11.0 t/ha of straw. Crop uptake was 200 kg N/ha, 94 kg P_2O_5/ha, and 320 kg K_2O/ha. It is worth noting the high N and potassium (K) uptake. This variety also extracted 71 kg calcium (Ca)/ha, 46 kg magnesium (Mg)/ha, and a large amount of sulfur (S), 22 kg/ha. Sulfur is not generally applied as fertilizer in Costa Rica.

Most rice varieties respond to N application, although the response is a function of variety, cropping system, and the N demand at specific growth stages. For example, maximum yield was obtained with 180 kg N/ha with cv. *CR-1821* under irrigated conditions, but with only 150 kg N/ha for cv. *CICA-4* under upland cultivation.

Regional N losses are high due to the elevated temperature and high rainfall conditions. Research determined that split N applications based on crop growth stage and nutrient need could reduce N losses to leaching or denitrification. Summarizing research results from different Latin American countries, best yields are obtained by applying 20 percent of the total N at planting time, 20 percent at tillering, and the remaining 60 percent at flower initiation. Field research has also demonstrated that equal or higher yields are possible with four split N applications, but the additional cost of application increases total production expenses.

Studies on the use of slow release N fertilizers found slightly higher

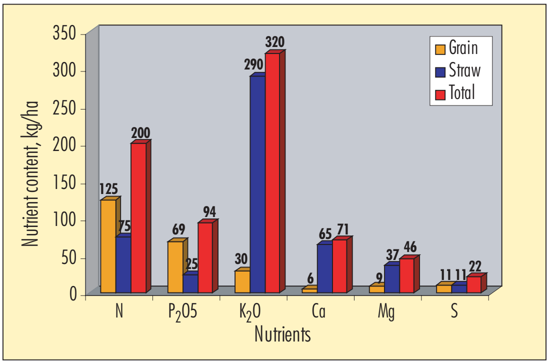

Figure 1. Nutrient removal by the CR-1821 rice variety in Costa Rica with a total dry matter yield of 20.3 t/ha.

rice yields compared to those obtained with straight urea. This advantage was associated with an apparent higher N recovery. The study also demonstrated that application of the entire N requirement at seeding resulted in a poor (18 percent) fertilizer use-efficiency. Nitrogen recovery was higher under irrigated conditions (40 percent) than upland conditions (35 percent).

Phosphorus (P) requirements for rice are relatively low; hence rates of application are also low, particularly in high pH soils. However, P is important in acid, low fertility soils. Under high yielding conditions, P is needed to balance the high requirement of N and K, even if the P content in the soil is relatively high. Phosphorus recommendations for rice grown under different soil conditions in the region are presented in **Tables 2**, **3** and **4**.

Potassium fertilizer requirements are related to soil K availability, the variety's K demand, and yield goal. Substantial amounts of K accumulate in rice straw (**Figure 1**) and are lost when straw is removed from the field. Incorporating crop residues recycles an appreciable amount of K, making it available for use by following crops, avoids K depletion, and maintains soil fertility. Despite the smaller quantity of K removed by harvested grain, farmers should account for this portion of K removed from the soil.

Correlation and calibration studies conducted in the region have established K rates needed in rice production. The critical K level is set at 0.1 $cmol_c/l$. Therefore, if soil tests are equal to or lower than this value, applications of 60 to 120 kg K_2O/ha are recommended depending on the soil type and K uptake requirement of the rice variety.

The critical K level in high pH soils is a useful tool for farmers, but it should be considered in combination with the Ca+Mg/K ratio. This parameter is important in Vertisols and in associations of Vertisols and Mollisols with high Ca and Mg contents. In these cases, an imbalance with K can develop resulting in responses to K application at soil K contents as high as 0.2 $cmol_c/l$. This is particularly true when the Ca+Mg/K ratio is greater than 204. This situation has been confirmed in Costa Rica

Table 2. Fertilizer recommendations for irrigated rice growing in Vertisols and Mollisols in Costa Rica.

		Potassium level, $cmol_c/l$								
		Low, <0.1			Medium, 0.11-0.20			High, >0.20		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
						kg/ha				
Phosphorus, mg/L	Low, < 5	180	60	60	180	60	30	180	60	0
	Medium, 6-10	180	30	60	180	30	30	180	30	0
	High, >10	180	0	60	180	0	30	180	0	0

P and K extracted with modified Olsen solution; N applied in three split applications.

where rice responses to applications of 80 kg K_2O/ha were evident in a Vertisol with a K content of 0.15 $cmol_c$/l and a Ca+Mg/K ratio of 273. Potassium recommendations for rice in different soil conditions in the region are presented in **Tables 2, 3 and 4.**

Table 3. Fertilizer recommendations for irrigated rice growing in Ultisols and Oxisols in Costa Rica and Colombia.

Phosphorus, mg/l	Potassium level, $cmol_c$/l								
	Low, <0.1			Medium, 0.11-0.20			High, >0.20		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	kg/ha								
Low, < 5	150	120	120	150	120	90	150	120	60
Medium, 6-10	150	80	120	150	80	90	150	80	60
High, >10	150	40	120	150	40	90	150	40	60

P extracted with Bray 2 solution; K extracted with ammonium acetate; N applied in three split applications.

Table 4. Fertilizer recommendations for upland rice growing in Ultisols and Oxisols in Costa Rica and Colombia.

Phosphorus, mg/l	Potassium level, $cmol_c$/l								
	Low, <0.1			Medium, 0.11-0.20			High, >0.20		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	kg/ha								
Low, <5	120	100	90	120	100	60	120	100	30
Medium, 6-10	120	50	90	120	50	60	120	50	30
High, >10	120	25	90	120	25	60	120	25	30

P extracted with Bray 2 solution; K extracted with ammonium acetate; N applied in three split applications.

Use of urea in upland rice and urea and ammonium nitrate in paddy rice has led to S deficiencies in many of the rice production areas of the region. In some cases, S becomes the yield-limiting factor. Correction of S deficiency is achieved with an application of 30 kg S/ha.

Zinc (Zn) deficiency is common in rice soils in Latin America and is related to low Zn availability, particularly in soils of high pH. The critical Zn level for rice in the region is around 3 mg/l (modified Olsen extraction).

Farmers in Latin America can only achieve maximum economic yield and maintain high soil fertility by practicing balanced and timely fertilization. **Table 2** shows nutrient recommendation for rice varieties grown under flooded conditions and high soil pH levels in Costa Rica with a yield goal of 6.5 t/ha. **Tables 3** and **4** show site-specific fertilizer recommendations for rice under irrigation and upland conditions in low pH soils of the eastern savannas of Colombia and are representative of soils throughout northern Latin America. **BCI**

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Rice Management and Fertilization in Entre Ríos Province

By Juan José De Battista

In the Entre Ríos rice production area, nitrogen (N) is the most limiting nutrient. Phosphorus (P) is usually supplied by the soil due to flooding. Response to potassium (K) is usually minimal.

Table 1. Rice in Argentina: area and production (1999/2000).

	Area		Production	
Province	'000 ha	% of country total	'000 t	% of country total
Entre Ríos	90.0	50.8	371.0	47.8
Corrientes	60.0	33.9	310.0	40.0
Santa Fe	15.6	8.8	50.5	6.5
Chaco	6.0	3.3	22.8	2.9
Formosa	5.1	2.9	20.1	2.6
Others	0.5	0.3	1.4	0.2
Total	**177.0**	**100.0**	**776.0**	**100.0**

Table 2. Area and production in Entre Ríos rice zones, 1999/2000.

Zone	Area, ha	Production, t
Northwest	5,400	17,000
North	35,100	160,000
Central	45,000	177,000
South	4,500	17,000

Rice in Argentina is grown primarily in the region between 27° and 33° south latitude and predominantly in the provinces of Entre Ríos and Corrientes, where almost 85 percent of total production is located (**Table 1**). The highest concentrations of production are in the north and central zones (**Table 2**).

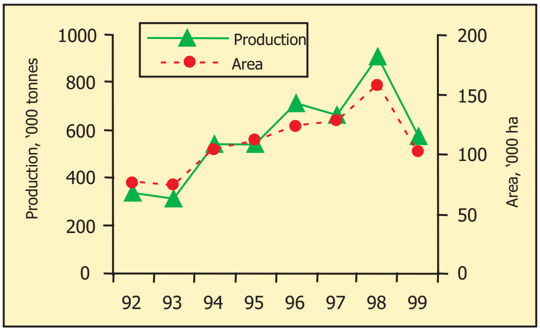
Rice area and production in Entre Ríos in the 1992-99 period increased through 1998 then declined in 1999 because of low prices (**Figure 1**).

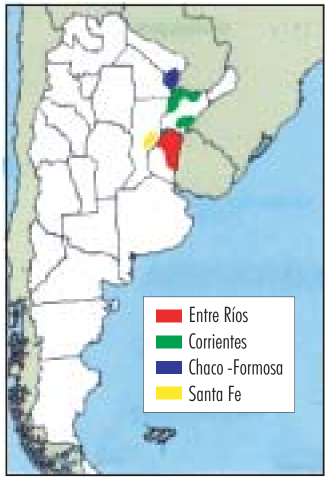
Approximately 400,000 tonnes of rice are annually consumed in the Argentinean market, with the remaining being exported mainly to Brazil, Iran and Peru.

Mean yields have been trending upward and increased from 4.6 t/ha in 1992 to 5.5 t/ha in 1999, with variations from year to year associated with climatic conditions. Low temperatures and rainy and cloudy days between the boot stage through to ripening diminish the percentage of matured grain and increase diseases such as *Pyricularia oryzae*.

Climate Entre Ríos can generally be characterized as having a wet, temperate climate, although the northern zone has a wet subtropical climate. Daily mean temperature is 18.5°C, with a maximum of 25°C in January and a minimum of 12.3°C in June. Annual precipitation of 1,200 mm is concentrated from October to April (73 percent of the total). Air humidity is greater than 70 percent.

Figure 1. Rice in Entre Ríos: area and production, 1992 to 1999.





Rice producing zones in Argentina.

Soils Northwest and north zone plains are Alfisols and Vertisols, characterized by a high montmorillonitic clay (40 to 50 percent) content in the B horizon, slow permeability, and hydromorphic conditions. Central and southern zone soils are undulating (slopes, 0.3 to 2 percent) Vertisols and Mollisols. The Vertisols show "gilgai" micro relief produced by expansion and contraction caused by changes in soil moisture. Mollisols have a silty clay loam, superficial horizon, and a clay B horizon similar to Vertisols. Vertisols are characterized by variable organic matter content (3 to 7 percent), higher than Mollisols, a low level of available P—less than 8 parts per million (ppm) Bray & Kurtz P-1—medium to high level of exchangeable K (greater than 250 ppm), and a total N content associated with soil use history (0.17 to 0.22 percent).

Production practices Rice is planted over a period of four months, from September to December. Drained soils are cultivated and leveled, and ditches are built six months prior to planting so pre-plant vegetation establishes before seeding. In the last decade, the availability of no-till seed drills has modified tillage practices whereby pre-plant vegetation is controlled with the herbicide glyphosate, and rice is seeded directly into the desiccated vegetation. Most commonly, 50 kg/ha of diammonium phosphate is applied with the drill at planting and 50 kg/ha of urea is top-dressed at panicle differentiation by aerial application. The irrigation schedule consists of one or two flushes during seedling growth to establish an adequate rice stand. Permanent flooding is established 30 to 40 days after emergence with 5 to 10 cm of water table until 15 days before harvest. In 70 percent of the rice area, irrigation water is pumped from deep wells (70 to 100 m) while the remaining area is irrigated with surface water, 25 percent from reservoirs and 5 percent from rivers.

Fertilization trials conducted during a 10-year period established the relationship between soil nutrient availability and rice yield response to N, P, and K fertilization. Randomized complete block experiments (three replications) were conducted on 50 farmer fields using four predetermined rice varieties: *San Miguel INTA, El Paso 144, IRGA 417,* and *Don Juan INTA*. Nitrogen rates of 0, 25, and 50 kg N/ha, as urea, were split-applied at tillering and panicle differentiation. Phosphorus rates of 0 and 30 kg P_2O_5/ha, as triple superphosphate, and K rates of 0 and 45 kg K_2O/ha, as potassium chloride (KCl), were applied at seeding.

Nitrogen fertilization improved yields in more than 70 percent of the trials. Mean responses were 23.4 and 15.7 kg rice per kg N for 25 and 50 kg N/ha rates, respec-

Rice fertilization trial at the central zone of Entre Ríos (variety IRGA 417, 20-day-old seedlings).

Table 3. Response frequency and mean yield response to N, Entre Ríos.

Varieties	N rate, kg/ha	Frequency		Mean response	
		R/N[1]	%	kg/ha	kg of rice/kg N
San Miguel INTA	25	6/8	75.0	453	18.1
	50	18/25	72.0	550	11.0
El Paso 144	25	9/12	75.0	540	21.6
	50	9/13	69.2	870	17.4
Don Juan INTA	25	3/7	42.9	710	28.4
	50	5/7	71.4	779	15.6
IRGA 417	25	3/5	60.0	632	25.3
	50	5/5	100.0	946	18.9

[1] R=response; N=number of trials

tively (**Table 3**). Yield increase was affected by variety, soil N supply capacity, amount of radiation during the reproductive phase, and management practices such as weed control and plant density.

Rice response to N was closely correlated with soil organic matter content. In 85 percent of the sites, yield responses to 50 kg N/ha were observed when soil organic matter was lower than 4.5 percent (**Figure 2**).

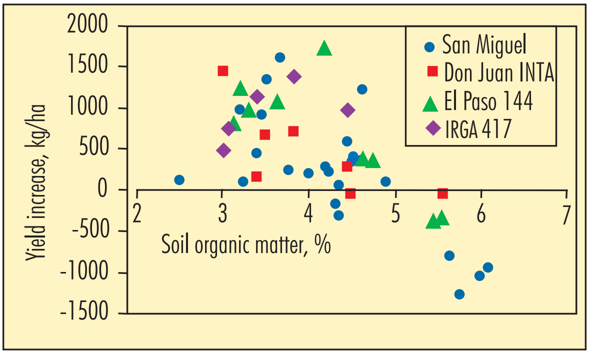


Figure 2. Relationship between soil organic matter content and rice yield increase with applications of 50 kg N/ha at Entre Ríos.

Phosphorus fertilization increased yields at 35 percent of the sites. The mean yield response varied from 8.7 to 29 kg rice per kg of applied P_2O_5. In most cases, soil P content was less than 8 ppm, and yield response was not associated with soil P content. When soils are flooded, reducing conditions mobilize P from ferric iron (Fe^{3+}) and aluminum (Al) phosphates to more labile forms and increases P mineralization from soil organic matter, both acting to satisfy the crop's P requirement.

Potassium fertilization increased yields in 20 percent of the trial sites. The mean yield response was 10.6 kg rice per kg of K_2O applied. The general lack of response to K application is attributed to high (greater than 250 ppm) soil exchangeable K content of the rice-growing soils.

Conclusions

Nitrogen is by far the most limiting nutrient in the Entre Ríos rice producing area. Results show it is reasonable to expect significant yield increases from N fertilization when soil organic matter content is below 4.5 percent. In most cases, P requirements are supplied by the soil, a positive effect due to soil flooding. Starter applications increase P uptake by the rice crop. Response to K fertilization was infrequent and minimal because of high soil exchangeable K contents. **BCI**

Harvest of experimental plots at a farmer field.

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Upland Rice Production in Brazil

By M.P. Barbosa Filho and T. Yamada

Most of the upland rice produced in Brazil is on Oxisols with low water-holding capacity and often with low fertility. This article outlines some of the management practices being studied for sustainable rice production systems.

Upland rice occupied 2.4 million ha or 64 percent of the total rice area in Brazil in 1999 (**Table 1**). However, due to lower productivity as compared with flooded rice, it contributes only about 38 percent of Brazil's total rice production.

The lower productivity of upland rice is attributed to dry spells during the crop season and low soil fertility. Higher risk due to dependence on rainfall discourages farmer investment in soil fertility. As a result, low soil fertility increases crop susceptibility to water stress and disease. Moreover, the Oxisols where upland rice is cultivated have low water holding capacity, with two-thirds or more of the available water being removed by suction of 0.1 to 1.0 atmospheres, regardless of soil texture (Lopes, 1977). Studies done at the national Rice and Bean Research Center in Brazil show that normal water deficits during the reproductive stage can reduce yield by 40 percent.

Table 1. Rice area and production in Brazil in 1999.

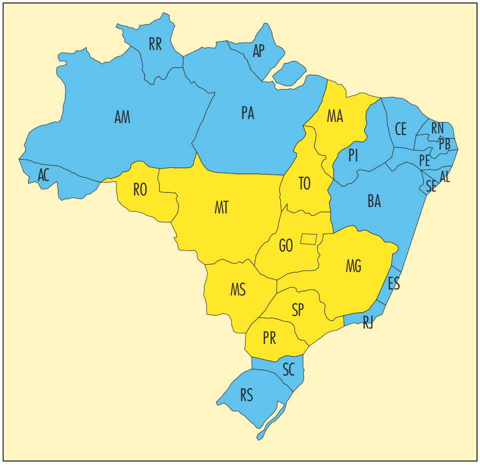
	Area		Production		Yield
Systems	'000 ha	%	'000 t	%	kg/ha
Upland	2,430	63.8	4,450	37.8	1,830
Flooded	1,310	34.2	7,180	61.0	5,500
Várzea[1]	75	2.0	144	1.2	1,920
Brazil	3,810	100.0	11,800	100.0	3,090

Source: IBGE – Levantamento Sistemático da Produção Agrícola, dez/1999.

[1] Várzea: low lands adjacent to rivers

Upland rice producing areas can be separated into two regions according to rainfall. The less risky area produces yields of 3 to 5 t/ha because of favorable rainfall and a medium/high technological level among farmers (comprising the states of Mato Grosso do Sul and Mato Grosso and the southern part of Pará and Maranhão states). The more risky area (comprising the states of São Paulo, Minas Gerais, Goiás and Tocantins, and the Federal District) produces yields of 1.5 to 1.8 t/ha and suffers one to two dry spells (veranicos) during the rainy season. Primary upland rice growing states are shown in **Figure 1**.

Figure 1. States growing mainly upland rice in Brazil (yellow area).



In the past, upland rice was grown mainly to prepare the land for pasture establishment. Continuous monocrop rice production and the associated excessive tillage, inadequate erosion control measures, and insufficient application of lime and fertilizer resulted in significant environmental damage and a non-sustainable crop production system.

Presently, upland rice is grown for about two years after clearing the cerrado vegetation, because the root residues do not permit mechanical harvest of soybeans. Therefore, upland rice is considered as a crop to "tame" cerrado soils before planting crops which are currently more profitable, such as soybeans and corn.

Most of the upland rice production area occurs on two Oxisol groups, *Dark-Red Latosol and Yellow-Red Latosol*, representing about 52 percent of the cerrado region. Characteristically, these soils are deficient in nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), manganese (Mn), and zinc (Zn). They are high in aluminum (Al), low in cation exchange capacity (CEC), and have a high P fixation capacity. Although these soils have a medium organic matter content, they are low in microbial activity due to low pH and high contents of iron (Fe) and Al oxides. (Lopes, 1977).

In general, these Oxisols have very good physical characteristics for plant growth: soil friability, porosity, permeability, and depth, all of which facilitate good root development. Topography varies from greatly to slightly undulated. Texture ranges from extremely clayey to extremely sandy. A characteristic of these soils is their low water holding capacity.

Liming

Residual effects of liming to either correct pH to 5.5 or for Al neutralization last for at least five years following application. Care must be taken to avoid excessive liming which causes deficiencies of all micronutrients, except molybdenum (Mo). Liming above pH 6.0 has been considered the primary cause of Zn and Fe deficiency in upland rice grown after a leguminous crop (Barbosa Filho et al., 1994).

According to Souza et al. (1986), the liming recommendation for central Brazilian soils with more than 20 percent clay content is calculated by the following formula:

$$\text{Lime (t/ha)} = Al^{3+} \text{ x } 2 + [2 - (Ca^{2+} + Mg^{2+})]$$

For soils with less than 20 percent clay content, the higher value obtained by either of the two formulas shown below is used.

(1) Lime (t/ha) = Al^{3+} x 2,
(2) Lime (t/ha) = $2 - (Ca^{2+} + Mg^{2+})$

The above calculations are based on lime with a relative neutralizing value of 100 percent and where Al^{3+}, Ca^{2+} and Mg^{2+} are expressed as $cmol_c/dm^3$ soil.

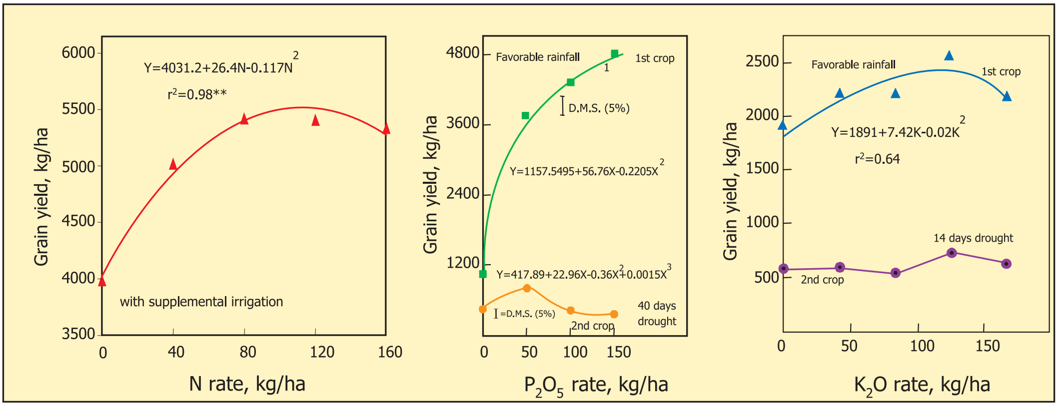


Figure 2a. Figure 2b. Figure 2c.

Figure 2. Upland rice response to N, P, and K fertilization under favorable rainfall and drought conditions on an Oxisol in west central Brazil (Fageria, 1980; Fageria et al., 1982; 1990; Stone et al., 1999).

NPK Fertilization

The yield response of upland rice to high rates of fertilization depends on favorable rainfall conditions or supplemental irrigation (**Figure 2a, 2b and 2c**). Application of N significantly increased the grain yield of four cultivars of upland rice in three consecutive crop seasons under supplemental irrigation. As shown in **Figure 2a**, the maximum grain yield of 5.5 t/ha was obtained with 113 kg N/ha (Stone et al., 1999).

For upland rice production in Brazil, P is the most important yield-limiting plant nutrient, due to the inherently low soil P levels and high P fixation capacities. Application of both P and K increases grain yield, but the effect is more pronounced under favorable rainfall conditions. In one study, P fertilization increased yield nearly five-fold with application of 150 kg P_2O_5/ha compared to the unfertilized control when moisture was sufficient (**Figure 2b**). Where drought severely limits yield response, similar non-responsive results are obtained with both P and K fertilization (**Figure 2c**).

Corrective P fertilization recommendations range from 50 to 240 kg P_2O_5/ha (broadcast and incorporated), depending on the P level and clay content of the soil (**Table 2**). Corrective K fertilization recommended by the Brazilian Agricultural Research Corporation (EMBRAPA) Cerrados, based on soil K level and soil clay contents greater than 20 percent, is presented in **Table 3**. It is recommended that K be broadcast to avoid leaching losses due to the low cation exchange capacity (CEC) of cerrado soils.

Maintenance fertilization varies with the production system, the amount of residue left by the preceding crop and the expected yield. In general, maintenance applications recommended are: 60 to 120 kg N/ha for one (clay soils) or two (sandy soils) applications, 60 to

Table 2. Soil P level and clay content affect corrective P fertilization.

Clay content, %	Soil P level, Mehlich I, mg/dm³		Corrective fertilization, P_2O_5, kg/ha	
	Very low	Low	Very low	Low
61-80	0-1	1.1-2.0	240	120
41-60	0-3	3.1-6.0	180	90
21-40	0-5	5.1-10.0	120	60
<20	0-6	6.1-12.0	100	50

Table 3. Corrective K fertilization as determined by soil K level and clay content greater than 20 percent.

Exchangeable K, mg/dm³	K_2O rate, kg/ha
0-25	100
26-50	50

120 kg P_2O_5/ha, and 30 to 90 kg K_2O/ha.

Micronutrients

Micronutrient deficiencies are widespread in central Brazil. Corrective rates for soil and foliar applications are recommended for B, Cu, Fe, Mn, Zn, and molybdenum (Mo).

Sustainable Production

The objective of EMBRAPA Rice and Bean Research Center efforts is to develop technologies for sustainable rice production systems that have the least negative impact on the environment. Technologies being tested include: no-tillage, crop rotation, nutrient management, integrated pests, diseases and weed control, efficient water use, and development of improved cultivars.

Farmland under no-till is increasing and already covers about 14 million ha. It is proving to be one of the most efficient ways to control soil erosion and to rebuild the fertility of degraded soils. However, many of the management practices adapted from conventional tillage systems, such as lime requirement and N fertilizer timing, need to be studied in no-till systems. **BCI**

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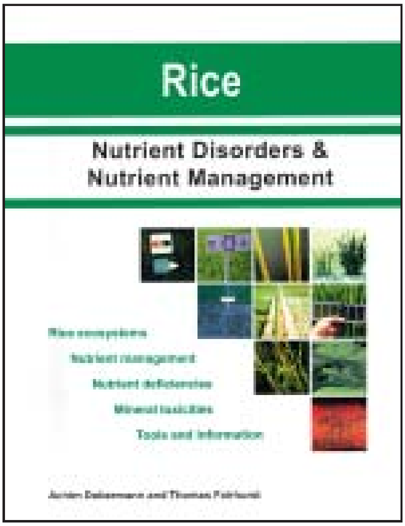
Handbook on Rice Nutrient Management Now Available



The International Rice Research Institute (IRRI) in the Philippines has forecast that rice yields must increase by 30 percent by 2020 to keep pace with growing demand for rice due to projected increases in world population.

A handbook published recently by IRRI and PPI/PPIC describes site-specific nutrient management methods and provides a reference to assist with the identification and management of nutrient disorders. Titled *Rice: Nutrient Disorders & Nutrient Management*, the 191-page book is authored by Dr. Achim Dobermann, formerly with IRRI and now with the University of Nebraska, and Dr. Thomas H. Fairhurst, Director, PPI/PPIC East and Southeast Asia Program (ESEAP), Singapore.

Oriented to production in tropical and subtropical regions, topics include rice ecosystems, nutrient management, nutrient deficiencies, and mineral toxicities. Estimates of nutrient removal in grain and straw are included to help researchers and extension workers calculate the amount of nutrients lost from the field under various management systems. The publication will improve understanding of new approaches to nutrient management at the farm level.

Descriptions of nutrient disorders in rice are enhanced by color photos and charts. Where appropriate, additional information has been included for upland rice and rice grown in flood-prone conditions.

The book includes an interactive CD-ROM and is available for purchase. For more details, visit the website at www.eseap.org, or contact Doris Tan, PPI/PPIC (ESEAP), 126 Watten Estate Road, Singapore 287599; e-mail: dtan@eseap.org, phone: 65 6 468 1143, fax: 65 6 467 0416. To order from the International Rice Research Institute (IRRI), visit www.irri.org/pubcat2000/pub2000-R2.htm#nutrient, or contact Division WB, CPS-Marketing and Distribution Unit, IRRI, DAPO Box 7777, Metro Manila, the Philippines; e-mail: e.ramin@cgiar.org or irripub@cgiar.org or fax 632 761 2404 or 632 761 2406. **BCI**

Life's Little Miracles

Whenever possible, I watch a Canadian television program which documents the fantastic medical advances and technology for rescuing children from debilitating and life-threatening infirmities. The show – from The Hospital for Sick Children, in Toronto – is aptly titled *Life's Little Miracles*. What I see holds me in awe. The scientific and technological capability is intriguing; the capacity of the kids, their parents, and the doctors to persevere against all odds…and to conquer…is the truly fascinating element of this program.

I feel the same when I travel and meet farmers and their families, most of whom are poor, uneducated, small landholders, who have experienced the power of science and technology in correcting nutrient deficiencies and raising high quality crop yields. They know prosperity is at hand. *Fertilizers…indeed another of life's little miracles.*

Rice is a major world crop with the distinction of being the staple food for many of the world's most populated and agriculturally challenged countries. PPI/PPIC published this special rice edition with the intention of showing the opportunity as well as the means for increasing both rice productivity and income for those farmers who persevere. There are many such farmers around the world…and it is time for them to conquer constraining soil fertility problems; it is time for them to experience the power of science and technology that can rescue them and their society from the debilitating conditions hunger causes.

This edition of *Better Crops International* is designed to help farmers and the agronomists working in both the field and research plots to understand the real need and the real opportunity for rice production. It is dedicated to those suffering with low yield and food insecurity symptoms. The information is written to document the miracles resulting from fertilizer…balanced and adequate use of fertilizers…to increase yields and food security, to raise the income of farmers, and to secure the environment. *Enjoy the miracle.*

Dr. Mark D. Stauffer
Senior Vice President,
International Programs, PPI
and President, PPIC

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