Economic prosperity in Asia: implications for rice research

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This paper describes the changing economic environment in Asia and the impacts these changes have on input-output markets and the organization of rice production in high- and low-income countries. Emerging problems in Asian rice farming—related to sustaining farmers' incentives in high-income countries and food security in low-income countries—are discussed. The author assesses the priorities for genetic rice research that will be required to develop appropriate technologies needed to address the problems. These priorities are grain quality, resistance to abiotic and biotic stresses, shifting the yield frontier, direct seeding for crop establishment, and incorporating micronutrients.

Rice is the staple food and the principal crop in humid and subhumid Asia. The monsoon climate and the high temperature during periods of heavy rainfall favor rice cultivation in this region. From the Philippines in the east to eastern India in the west and from southern China in the north to Indonesia in the south, rice accounts for 30-50% of agricultural incomes and provides 50-80% of the calories consumed. Because of its importance in providing national food security and generating employment and incomes for the low-income people in society, rice is regarded as a strategic commodity and an important component of culture in many Asian countries. More than 90% of all rice is produced and consumed in Asia. The world rice economy is thus dominated by the economic environment in Asia.

Two contrasting developments in Asia may substantially affect the structure of rice production and marketing. First, the prosperous Asian countries are finding it difficult to sustain producers' interest in rice farming. The move toward free trade in agricultural production, initiated by the recently concluded General Agreement on Tariffs and Trade (GATT), will have important implications on the sustainability of rice farming in these countries. Second, the potential for increased productivity created by the dramatic technological breakthroughs in the late 1960s has almost been exploited, particularly for the irrigated and favorable rainfed environments. But poverty in low-income countries is still extensive and population continues to grow at a high rate. As rice production is losing the race against population, sustainability of self-sufficiency in rice production is becoming a major issue for the land-scarce, low-income countries.

Rice research: achievements and future challenges

Genetic improvements in the rice plant made a great contribution to achieving food security in Asia over the last 3 decades (Hossain and Fischer 1995, Khush 1995). The large shift in the yield potential of rice and the reduction in the period of crop growth have made up for the limited availability of land in Asia and have empowered farmers to increase rice supplies. In most Asian countries, average rice yields have continuously increased since the mid-1960s as farmers replaced traditional varieties with improved ones. Incorporation of resistance against major diseases and insects in the modern varieties (MVs) has ensured the stability of rice yield and prices and reduced the risks of cultivation and farmers' dependence on harmful agrochemicals.

Since 1966, when IR8 was released, the Asian population has increased by 85% but rice production has doubled leading to some increase in per capita consumption. Technological progress has led to a downward trend in the unit cost of production and prices. The price decline benefits the vast number of urban poor and the rural landless who spend more than half of their incomes on staple foodgrains. Although profits per unit of output have declined in many countries, the rice farmers were able to increase household incomes through an expanded output from two or three crops grown on the same land and a larger size of each crop. The technological progress thus helped maintain a balance in the interests of consumers (lower prices) and producers (higher incomes).

But the race between rice production and population growth is far from over. Asian population is still growing at 1.7% yr^{-1}, and is projected to increase by another 85% before stabilizing by the end of the 21st century. In fact, in the 1990s, Asia will see the largest absolute increase in population (53 million annually) in the history of mankind. Even if per capita rice consumption is kept at the present level, rice supplies must increase at the rate at which population grows; otherwise there will be an upward pressure on prices. Also, as economic growth and better distribution of income increase the capacity of the Asian poor to satisfy their unmet food needs, per capita rice consumption is expected to increase further, particularly in low-income countries. It is projected that during the 1990-2025 period, the demand for rice may increase by another 70%, which will require an increase in production from 480 million t of unmilled rice at present to 810 million t by 2025 (IRRI 1993, Rosegrant et al 1995). Most of the additional demand will come from the low-income countries of Asia, where there is still substantial unmet demand for rice, and the success in population control has remained limited.

It is true that over the last 3 decades the increase in rice production was greater than what is needed for the next 3 decades. So the challenges may appear to many observers as less daunting. But, easy options for both technological changes and the utilization of the natural resources (i.e., more intensive use of land and water) have already been exploited, and further exploitation of natural resources may turn out to be uneconomic and more harmful for the environment (Rosegrant and Svendsen 1991, Cassman and Pingali 1995). Also, the fast economic growth in different parts of Asia and the difference in economic landscape have been affecting the availability and the costs of agricultural inputs, and the relative prices and profitability of outputs that have important implications on the production and marketing of rice. In view of the changes in economic environment, the rice research community should reconsider the strategy and priority for technology development.

Economic prosperity and organization of rice production

Economic growth in Asia

The remarkable progress of the Green Revolution in rice cultivation went hand in hand with enormous economic progress in many parts of Asia. Economic growth in Asia has been many times faster than that for other regions in the developing world. Since 1970, the average annual rate of growth has been a robust 6.0% annually in Asia, compared with 3.2% in South America and 2.4% in Africa (World Bank 1995). A rate of population growth of more than 2.5% yr^{-1} has eaten up the meager growth in Africa, so most African nations have seen a deterioration or stagnancy in the economic conditions for their people. In contrast, economic growth in many Asian nations has also contributed to notable progress in population control, which has been reflected in faster growth in per capita incomes. With an annual rate of growth of about 5% yr^{-1}, the per capita income of Asian people has doubled every 14 yr since the early 1960s.

The rate of economic progress has, however, been uneven across countries in Asia. The growth has been much faster in East Asia compared with Southeast Asia, which in turn has grown faster than South Asia. In Southeast Asia, economies in the Philippines, Myanmar, Cambodia, and Lao PDR grew much slower than Thailand, Malaysia, and Indonesia. There was also a positive relationship between overall economic growth and the development of the agricultural sector (Fig. 1). But it is the faster growth of the nonagricultural sectors that has contributed to the vast economic prosperity in Asia.

In 1950, Asian countries had almost identical economic standings, with the exception of Japan. But because of uneven economic growth, substantial economic disparity has been created. For example, in the early 1960s, the Philippines had higher levels of income than the Republic of Korea. Now, Koreans have incomes eight times higher than Filipinos. As the economy grew, the importance of agriculture declined, vibrant manufacturing and service sector activities pulled labor force and population from rural to urban sectors, and higher income levels and larger participation of women in economic activities reduced the demand for children and lowered the population growth. The economic disparity among Asian nations, the importance of agriculture, and the structure and the growth of population can be seen in Table 1.

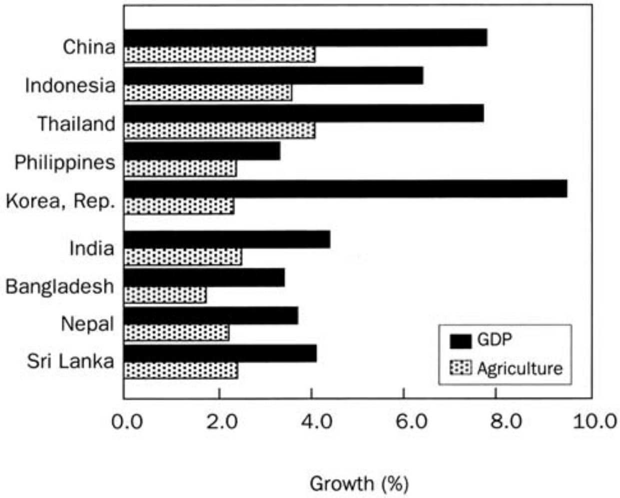

Fig. 1. Growth of economy and agriculture, selected countries of Asia, 1970-93.

Table 1. Economic disparity and the growth and structure of population in major rice-growing countries, 1993-94.

Country	Production of rice unhusked 1994 (million t)	Per capita Income 1993 (US$)	Agriculture's share of the economy, 1993 (%)	Population growth 1990-95 (% yr^{-1})	Urban population 1993 (%)
China	178.3	490	19	1.2	29
India	118.4	300	31	1.9	26
Indonesia	46.2	740	19	1.6	33
Bangladesh	27.5	220	30	2.0	17
Vietnam	22.5	170	29	2.2	20
Myanmar	19.1	59	63	2.2	26
Thailand	18.4	2,110	10	1.4	19
Japan	15.0	31,490	2	0.3	77
Philippines	10.2	850	22	2.4	52
Korea, Rep.	7.1	7,660	7	0.9	78

Source: World Bank (1995).

Effect on input markets

The growing economic prosperity in Asia is a crucial factor that determines the availability of labor, water, and land for rice cultivation. The competing demand for these inputs in various economic activities affected their relative scarcities and prices and changed the relative profitability depending on the intensity of use of these inputs in various economic activities.

Labor and wages. Economic growth brings dramatic changes in the structure of employment, adoption of labor-saving technology, and increase in labor productivity.

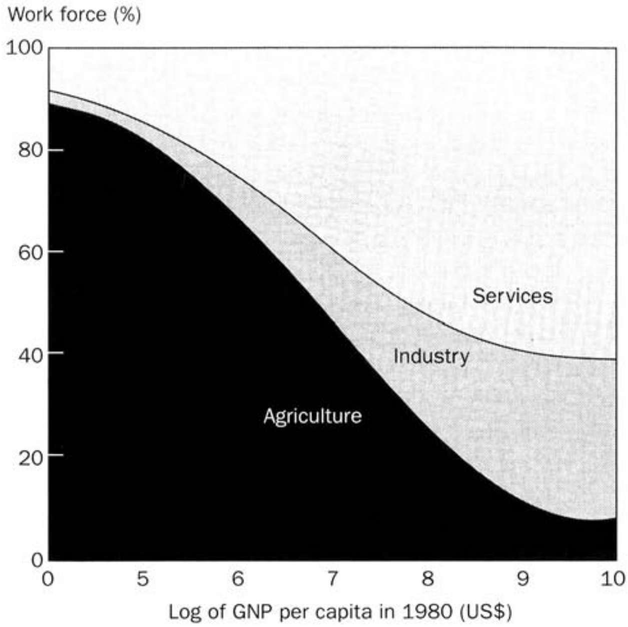

Fig. 2. Relationship between sectoral distribution of labor force and level of economic growth.

The working age population, which is the source of supply of labor, is determined by the rate of population growth and female participation in economic activities. In most developing countries, the rate of growth in the working age population has been around 2-3% annually (World Bank 1995). A faster rate of economic growth than this rate has led to severe competition for labor among economic sectors in Asia, because demand grew at a faster rate than supply. With opportunities for more remunerative employment rising elsewhere, workers move out of low-productivity, low-wage rural economic activities.

The relationship between the sectoral distribution of the labor force and the level of economic growth analyzed by the International Labor Organization is shown in Figure 2. On average, agriculture's share of employment falls from 90% of the total in low-income countries to roughly 5% in high-income countries. The share of industry, which includes manufacturing, construction, and mining, increases from 4 to 35%, and that of services from 6 to 60%. As the economy grows faster, the pull of labor in the manufacturing and services sectors away from agriculture becomes stronger, and after some time, the labor force employed in agriculture declines in absolute terms.

Although the agricultural sector tries to address the problem of labor shortages by adopting labor-saving technologies, it cannot compete with the manufacturing and services sectors in this respect, so the productivity differences continue to grow with economic prosperity. The total agricultural labor force increased from 4.5 to 6.1 million persons during the 1966-75 period, and then started declining in absolute terms and reached 3.2 million by 1990 (World Bank 1995).

The scarcity of labor is reflected in its price—the wage rate (World Bank 1995). In sub-Saharan Africa, where economies have remained stagnant, the real wages hardly increased during the 1970-90 period. In contrast, in East and Southeast Asia, which experienced more than 5% yr^{-1} growth in per capita incomes, the real wage rate increased by 170% over the 20-yr period. In South Asia, where the economic growth was moderate, the real wage rate increased by only 50%.

Rural-urban migration, increase in labor productivity, and escalating wage rates in the nonfarm sector put an upward pressure on the rural wage rate, which affects the costs of production and profitability in rice cultivation. The growth in the agricultural wage rates over the 1961-91 period for selected Asian countries is shown in Table 2. In the early 1960s, the difference in wage rate across countries was only marginal. In the slow-growing countries, such as Bangladesh, India, and the Philippines, the agricultural wage rates had hardly increased, but there was an escalation in wage rates in Japan and the Republic of Korea.

Availability of water. Water resource development has been the key to increasing rice production in virtually all Asian countries where land is a scarce factor of production. Among all activities involving exploitation of natural resources, irrigation is by far the most important. Asia accounts for 55% of an estimated 253 million ha of irrigated land in the world; China and India alone have more than 100 million ha of irrigated land (Fredericksen et al 1993).

Water has always been regarded as an abundant resource for humid Asia. But with rapidly increasing populations, the substitution of water for scarce land has taken place to meet the food needs. As a result, the perception of abundance of water has been changing in many Asian countries. The per capita availability of water resources declined from 40 to 60% in most Asian countries over the 1955–90 period (Feder and Keck 1994). By common convention, countries are defined as water-stressed when the availability is between 1,000 m^3 and 1,700 m^3 per capita. Projections based on constant availability of water and increasing population suggest that China, India, Sri Lanka, Pakistan, and the Republic of Korea are expected to reach near stress levels by 2025.

An important issue for Asia is the spatial and seasonal dimension of the problem of water availability. Rainfall varies across countries and among regions within a

Table 2. Long-term trend in wage rates, selected Asian countries. (US\$ d^{-1}).

Country	1961	1971	1981	1991
Bangladesh	0.46	0.44	0.86	1.39
Philippines	1.39	0.59	1.51	2.16
Korea	0.82	1.86	10.84	32.59
Japan	1.22	8.19	24.16	51.93

Source: IRRI (1995).

country. About half of China receives less than 400 mm of rainfall annually; extensive areas of northwestern and central India and central Myanmar are classified as drought-prone. Most of the Asian region receives rainfall predominantly during a single monsoon lasting from 4 to 6 mo, with almost no rain for the remainder of the year. The marked seasonality of rainfall means that, if reservoir storage is not provided, much of the runoff generated is destined to flow, wasted, into the ocean. The monsoon is often erratic. Floods and seasonal water shortages occur in the same year in many countries. Estimates based on water availability during the dry season show that most countries will be water-stressed within the next 30 yr.

As population increases and economic development intensifies, satisfying the needs for drinking water, sanitation, and industrial activities has to be given higher priority in allocating water resources. As rice is a heavy consumer of water, rice research can contribute to saving this important natural resource, as demands for water in other competing and more productive uses increase with economic growth.

Competing demand for land. Economic prosperity and industrial progress are leading to rapid urbanization and concentration of people in a few large cities. Most of the additional increase in population beyond 2000 will be located in urban areas. By 2025, 53% of the people in Asia will live in urban areas compared with 30% in 1990 (UN 1993). An important implication of growing urbanization is that some of the fertile agricultural land has to be diverted to meet the demand for housing, factories, and roads. Also with urbanization and the associated change in food habits, the markets for vegetables, fruits, and livestock products will grow stronger. The growing market for livestock products will increase the demand for livestock feed (maize) and fodder. The changes in relative profitability will induce farmers to divert riceland to grow more profitable nonrice crops such as vegetables, fruits, and fodder. The area under riceland has already started declining even in low- and middle-income countries such as China, the Philippines, Indonesia (Java), and Bangladesh.

Output market: quantity vs quality

Studies on consumption behavior show that per capita rice consumption largely depends on urbanization, the level of income, and changes in occupational structure. At very low levels of income, people take coarse grains and sweet potatoes as their basic staple, as these are usually the cheapest sources of energy. As income increases, per capita rice consumption grows since people can afford to substitute these low-cost sources of energy for rice. But there is a threshold level of income beyond which rice becomes an inferior good. As incomes rise further, consumers aspire to have a more balanced diet with high-cost quality foods such as vegetables, bread, fish, and livestock products that provide proteins and vitamins, along with calories. So the per capita rice consumption starts declining.

Another notable pattern of rice consumption is that with growing incomes, people express preferences for higher quality rice once their calorie needs have been met. High-income consumers spend more on rice by paying higher prices for the varieties with preferred eating quality.

As rice scientists have had limited success in developing high-yielding cultivars with better eating quality, the price difference between the standard and high-quality varieties has been growing in Asian markets.

Emerging problems in Asian rice farming

Sustaining farmers' incentives in high-income countries

Despite the impressive increase in land productivity, it has been difficult for the fast-growing Asian countries to sustain producers' interest in rice farming. As mentioned earlier, the expansion of the nonfarm sector and the rapidly rising labor productivity have pushed up nonfarm wage rates, which attracted labor from rice farming and increased agricultural wages. Since traditional rice farming is a highly labor-intensive activity, the pressure from the nonfarm sector has pushed up the cost of rice production and reduced profits and farmers' incomes. In Japan, Taiwan, and the Republic of Korea, the constant outflow of the agricultural labor force has caused a continual decline in the farming population (Park 1993). Aging of labor force and depopulation in remote areas have continued, making it difficult to sustain the existing rural communities in some areas.

The competitiveness of rice farming has sought to be maintained through 1) improved farm management practices that increase efficiency in the use of nonland inputs and increase total factor productivity, 2) increased use of capital to replace labor through mechanization of farming operations so that labor productivity could be raised when no further increase in land productivity is possible, and 3) using the price mechanism to transfer income from the relatively well-off rice consumers to the rice producers so that the balance between the rural and urban incomes could be maintained.

The protection of the domestic rice industry encourages high-cost domestic production. The cost of producing rice in Japan is about 17 times higher than in Southeast and South Asian countries and about 10 times higher than in the USA. The recently concluded Uruguay round of trade negotiations has increased pressures to remove rice subsidies and to partially open up rice markets in East Asia. As the economic prosperity in East Asia depends on liberalization of trade of industrial products, these countries may yield to the pressure to move toward free trade in agricultural commodities. In this case, domestic prices of rice will fall and the rice industry will be threatened. These countries will then depend more on imports for meeting their grain needs. They have the economic capacity to pay for such imports, but their riceland would remain fallow and other countries will have to produce an exportable surplus. Under this scenario, the price of rice is expected to increase substantially in the world market, which will redistribute scarce grain supplies in favor of high-income groups, leading to an escalation of poverty in the low-income, rice-growing countries.

Farm household income from rice farming could also be increased through removing legal restrictions on the ceiling of landholding. This will pave the way toward more enterprising farmers to accumulate land through tenancy arrangements or outright purchase from those who are interested in taking up full-time nonfarm occupations. The accumulation of land will increase farm household incomes even when profits per unit of land remain unchanged or decline. In fact, the main advantage of the American and Australian rice farmers over those in East Asia is the substantially larger farm size.

Sustaining food security in low-income countries

For the low-income countries of Asia, the emerging problem is how to ensure an increase in food supplies to meet the growing demand, and to maintain the capacity of all sections of the population to acquire that food. The challenge will be more acute for those countries that have a large proportion of area under an unfavorable rice-growing environment (Hossain 1995).

The per capita rice consumption is expected to increase faster in the poverty-stricken countries, as people satisfy their unmet food demand with economic growth. The experience of economic development shows that the lower the level of income, the higher the rate of population growth and that success in population control comes with economic prosperity. The low-income countries of South Asia and Southeast Asia (Vietnam, Myanmar, and the Philippines) are projected to have much higher rates of population growth and demand for food than the middle- and high-income countries in East and Southeast Asia. The demand for rice will remain almost the same in the Republic of Korea and will fall by 15% in Japan because of the decline in per capita consumption, but will increase by more than 70% in Bangladesh, Myanmar, and Vietnam and 60–70% in India and Indonesia (Hossain 1995).

The natural resource constraints to increasing rice production are severe for most of the low-income countries in Asia. As the frontier of cultivable land was closed long ago, the per capita availability of arable land has been declining rapidly with growing population. In its rice-growing region, China now supports 17 persons ha^{-1} of arable land; the figure is 13 for Bangladesh, 11 for Vietnam, and 8–10 for India, Indonesia, and the Philippines (Hossain 1995). Only Thailand, Myanmar, and Cambodia have favorable endowments of land, with 2–4 persons ha^{-1}. The population pressure is reflected in the high cropping intensity for foodgrain production. The cropped area under foodgrains per unit of arable land is 148% for China, 132% for Bangladesh, 112% for India, and 108% for Vietnam, compared with about 60% for Thailand and Myanmar.

As per capita rice consumption declines with economic growth, the middle- and high-income countries of Asia should have some surplus rice available for export to the low-income, food-deficit countries. In Japan, peak rice harvest reached 18.8 million t in 1967, but it started declining from that level and fell to about 12 million t in 1992. In Taiwan, China, the peak reached 3.6 million t in 1976; present production is only about 2.0 million t. These countries could have maintained their production levels through export of surplus rice to other countries, but they could not compete in the world market with other exporting countries because of the high production costs under protected markets. Thus, having an export surplus from middle- and high-income countries in Asia (where per capita rice consumption is expected to decline) to meet the deficits of the low-income countries seems highly improbable.

Thailand, Myanmar, and Cambodia have considerable excess capacity to meet potential shortages in other countries in South and Southeast Asia, and the cost of production will remain competitive for a long time, at least in Myanmar and Cambodia. If rice prices go up, farmers will be encouraged to increase production by investing in irrigation and chemical fertilizers and adopting higher yielding varieties.

But achieving food security through international trade may not be possible due to foreign exchange constraints in the low-income, food deficit countries. Also, since rice production is a major rural economic activity at low levels of income, and land and labor cannot be easily diverted to other economic activities during the monsoon season, low-income households may find it difficult to acquire imported food. If economic conditions of small-scale farmers and landless laborers fail to improve due to stagnant productivity of this most important economic activity, the increase in rice prices will only aggravate the poverty situation in the food-deficit countries.

In short, the ability of the low-income countries to feed its growing population will depend on increasing rice yields in the vast rainfed lowlands than on importing rice from other countries.

Implications for prioritizing research

This section presents the author's assessment of the priorities for genetic research that will be required to develop appropriate technologies needed to address the problems just discussed.

Grain quality

Improving grain quality of MVs is the most pressing need of the time. As Asians become richer, they are not going to eat more rice, but are willing to pay higher prices for rice that tastes better. Farmers are concerned as much with yields as with prices, since both of them determine profits. Rice varieties that combine superior grain quality with high-yielding ability will be in great demand everywhere. With rapid urbanization, the market for superior grains is growing among the high-income consumers of low-income countries. Also, as rice production is becoming uneconomical in high-income countries, the farmers in low-income countries could gain by producing exportable surplus of superior quality grains for the markets in high-income countries.

Research on breeding for quality has to be country-specific. But international genetics research could help identify traits that determine rice quality—the size and the shape of the grain, chalkiness, amylose content, gel consistency, and aroma. Rice breeders in national research systems could then use this knowledge to develop varieties for their respective countries.

Resistance to stresses

Abiotic. Almost half of Asia's riceland is dependent on rainfall and is subjected to both droughts and submergence, sometimes during the same season. Even if sufficient moisture is received over the growing season to support the physiological needs of the crops, the precipitation may not be evenly distributed to satisfy water requirement at various stages of crop growth. The uneven distribution of rainfall may result in temporary flooding and waterlogging from heavy rains particularly in areas with poor drainage, and dry spells in between leading to drought conditions. Even in areas where irrigation facilities are available, the supply of water may be unstable or inadequate to meet the crop's physiological needs, and hence, exposing the crop to the vagaries of the monsoons.

Many traditional varieties have developed traits through centuries of evolution that enable them to withstand these abiotic stresses. Rice scientists have so far had limited success in identifying these traits and incorporating them into high-yielding MVs (Zeigler and Puckridge 1995). The available MVs may do well in normal years, but may perform poorly compared with traditional varieties, if there is a prolonged drought or sudden submergence due to an erratic monsoon. So where the rainfall is unreliable, farmers still grow traditional varieties, which is the main factor behind the low yield and the large yield gap at the national level.

Several national agricultural research systems have recently conducted surveys recording perceptions of experienced farmers and extension workers on losses of rice yields from droughts and temporary submergence (Dey and Upadhaya 1994, Herdt 1996). The losses are estimated at 130 kg ha^{-1} from drought and 110 kg ha^{-1} from temporary submergence. In many countries, yield losses from abiotic stresses are higher than losses due to insects and diseases. Biotechnology has much to offer for the improvement of varieties for abiotic stresses (Bennett 1995). Although locating the minor genes is a difficult task, it is likely that in the long run, this approach will bear fruit, as it relates to many of the traits that plant breeders find difficult to deal with by conventional methods.

If rice research succeeds in incorporating modern traits that help withstand abiotic stresses, MVs will be adopted more extensively in the unfavorable ecosystems. The yield stability of these MVs will reduce risk in rice cultivation, thereby providing incentives to farmers to apply chemical fertilizers in optimum amounts, that will, in turn, lead to further yield increases.

Biotic. Over the last 2 decades, incorporating resistance in MVs against insects and diseases has been a top research priority. Many MVs have already been developed with multiple resistance to insects and diseases (Khush 1995). Host plant resistance is the cornerstone of effective pest management. Combining varietal resistance with biological agents and cultural practices can reduce use of harmful agrochemicals (Heong et a1 1995). Because of the substantial progress made in this area, farmers no longer perceive biotic stresses as major problem areas (Herdt 1996).

But resistant varieties do not remain resistant forever. So research must continue to sustain past developments and to find innovative and more cost-effective ways of controlling biotic stresses. There is a need to continuously identify new genes for more durable resistance and incorporate them into the improved germplasm. Biotechnology tools can be more effective in characterizing insect and pathogen population structure and in developing more durable host plant resistance through pyramiding of major genes and combining of quantitative traits (Bennett 1995).

Shifting the yield frontier

The yield potential of rice has hardly increased after the introduction of IR8, which kicked off the first generation of MVs. Once the potential yield (the economically optimum yield is much lower than the technical optimum) under the optimum management condition is reached in farmers' fields, the rice yield remains stagnant. In Japan and the Republic of Korea, rice yields have remained stagnant at around 6.5 t ha^{-1} after reaching that level long ago. China will soon approach that limit.

Rice breeders have recently given attention to shifting the yield frontier by changing the plant architecture and incorporating hybrid vigor. Much progress has already been made and it is projected that the potential yield could be increased by another 50% through this method (Virmani 1994, Khush 1995).

Farmers in high-income countries, however, are looking for MVs and farming practices that increase the productivity of labor rather than productivity of the land. Since the population is relatively stagnant and the per capita consumption of rice has started declining, more riceland has to be kept fallow if the yield increases, which will increase the governments' fiscal burdens on account of agricultural subsidies. Also, if liberalization of agricultural trade takes place, even a 50% increase in yield may not be enough to compensate for the drop in prices and thereby to help sustain farmers' incentives in rice cultivation. Hence, the demand for MVs with higher yield potentials may be slack in East Asian countries.

Varieties with higher yield potential will, of course, have a great demand in the low-income countries, as these will enable them to obtain more rice from the irrigated ecosystems where the yield levels of existing varieties are approaching the plateau. But this will further accentuate the regional inequality in agricultural growth contributed by the Green Revolution that has benefited the favorable rice-growing environments. The higher yield may also require larger use of agrochemicals on lands where these are already used in large amounts, and hence will not be environment-friendly. Thus, in view of the equity, food security, and environmental concerns, it is preferable to develop technologies that help reduce the existing yield gaps, than to increase yields for the favorable environments that will help already better-off farmers.

Support direct-seeding method of crop establishment

The direct-seeding method of crop establishment requires less labor and water, and hence is an appropriate technology for economies where labor and water are getting scarce. Puddling of soils for transplanting of seedlings consumes a large proportion of the estimated 5,000 L of water required to produce 1 kg of rice. In rainfed systems, farmers wait for heavy rains that flood rice paddies for puddling the soil. The delay in planting exposes the crop to drought at the reproductive stage of the plant growth and reduces the yield of the nonrice crop that follows rice. Direct seeding introduces flexibility of timing in crop establishment and contributes to more efficient use of the rain water.

However, to be acceptable to farmers, water science and agronomy research in this area needs to be supported by genetic research for introducing early seedling vigor in rice plants, to save them from sudden submergence during periods of heavy rains. Direct seeding also encourages weed growth, and there is a need to look for genetic traits that make rice more competitive with weeds. Although weeds can be economically controlled by herbicides, new ways of controlling weeds are required because of changes in the weed flora, herbicide resistance, and growing public concerns about the harmful effects of pesticides on human health and the environment (Rola and Pingali 1993, Pingali and Roger 1995).

Incorporating micronutrients in rice

In spite of substantial increases in per capita food intake and impressive reduction in poverty and hunger, the nutritional deficiency-induced diseases are widely prevalent in Asia (WFC 1992). These include child blindness due to Vitamin A deficiency, endemic goiter caused by iodine deficiency, and anemia caused by iron deficiency. The latest estimates based on country surveys suggest that, worldwide, at least 190 million preschool children are at risk of having vitamin A deficiency with about 350,000 victims becoming blind each year. Iodine deficiency usually occurs in mountainous regions and flood-prone areas where iodine easily leaches from the soil. Worldwide, some 1 billion people are at risk with iodine deficiency; 225 million of them have goiter. The problem is most serious in South and East Asia. Bouis (1994) has shown that low micronutrient intakes are a more important constraint to better health and nutrition than low calorie intakes for the Asian population.

As Asian people consume substantial amounts of rice (150 kg annually), small amounts of these micronutrients in rice could effectively address this nutritional problem. Thus, screening rice varieties for availability of the micronutrients and incorporating them into MVs without reducing the yield and quality of rice would definitely be a high-impact area of genetic research, although the probability of research success may be low.

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