Rice Research in India and the Asian Perspective

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Rice, *Oryza sativa,* is the staff of life for the population in Asia, particularly in South and Southeast Asia where more than 90 per cent of rice is produced and consumed. It is also a major source of livelihood for more than 250 million households. Providing adequate food entitlements, safeguarding public health, and at the same time preventing deforestation and conserving the environment are daunting challenges in the new millennium for countries in Asia, especially India where the population has already crossed the billion mark. Rice is the major source of calorie intake and also contributes to the total agricultural income in most of the Asian countries. World-wide, rice is grown over 153.766 M ha (Maclean *et al.* 2002). In Asia, rice is grown in 136.642M ha. India has the largest area (44.6M ha) under rice in the world and is second only to China in terms of rice production. It is the staple food of 65 per cent of the total population in India. It constitutes ca. 52 per cent of the total food grain production and 55 per cent of total cereal production.

Over the pasts three decades, the advent of modern high yielding rice varieties and associated Green Revolution technologies have almost doubled the rice production in South and Southeast Asia. Several

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countries in the region have not only achieved self-sufficiency in rice production, but also a few of them, including India, have become net exporters of rice. However, with the growing population, the demand for rice will also continue to grow. A challenge in the future would be that more rice would have to be produced from less land, with less water, less labour, and lesser use of pesticides. This would require innovative research and technologies and policies that promote increased rice production. Here we analyse the current status of rice production and review the constraints, opportunities, and advances in rice research and developments as well as some emerging concerns to meet the targeted production of rice in South Asia, especially India.

Rice Demand and Supply Scenario

With increasing population and increasing incomes, the demand for rice will continue to grow in coming decades. The population of South Asia, which was about 1.1 b in 1990, is expected to increase at a rate of 1.8 per cent and reach 1.9B by 2020 (Rosegrant *et al.* 1995). In spite of a slightly slower population growth rate of 1.7 per cent, the population in India will cross the 1.3B mark by 2020 and might overtake the population of China by 2035. Consequently, the demand for rice will grow and, hence the production must also increase. In 1990, the total rice production in South Asia was 101M tonnes and the demand was 99M tonnes, leaving a surplus of 2M tonnes. By 2020, rice production is projected at 197.62M tonnes as against a demand of 197.59M tonnes. Thus, rice production and demand will almost be balanced in contrast to a surplus of 2M tonnes in 1990 (Table 1). This could be attributed to somewhat a reduced rate of production growth, especially in Pakistan and Bangladesh. Although India and Pakistan will have a marginal surplus, but if the total factor productivity decelerates, they could also face a deficit in rice supply. For Bangladesh, a deficit of about 1 to 2M tonnes has been predicted by 2010 (Shahabuddin 2000). If the rate of growth in rice production is not sustained at the predicted levels, then the gaps between demand and supply could increase to 3M to 6M tonnes. On the whole, the rate of growth in production will be slower than the rate of growth in demand. Also, the demand for growth rate of rice in South Asia will be higher than the average rate projected for developing countries as a whole.

The per capita calorie intake in South Asia will improve from 2297 kilo-calorie in 1990 to 2640 kilo-calorie in 2020. Therefore, during that

Table 1. Projected population, demand and net supply of rice in South Asia , Southeast Asia and the world for 1990 to 2020

Country/ region	1990					2020					Growthrate	
	Area (‘000 ha)	Yield (mt/ ha)	Production (‘000 mt)	Demand (‘000 mt)	Net supply (‘000 mt)	Area (‘000 ha)	Yield (mt/ ha)	Production (‘000 mt)	Demand (‘000 mt)	Net supply (‘000 mt)	Production (‘000 mt)	Demand (‘000 mt)
India	42,321	1,781	75,388	74,758	630	44,237	3,293	145,777	144,792	985	2.22	2.23
Pakistan	2,594	1,329	3,448	2,101	1,347	2,918	2,127	6,207	5,309	898	1.98	3.14
Bangladesh	10,303	1,814	18,689	18,115	574	10,944	3,479	38,204	38,204	-132	2.40	2.52
Other S A countries	2,161	1,807	3,905	4,341	-436	2,244	3,369	7,561	9,283	-1,721	2.23	2.57
South Asia (total)	57,379	1,768	101,430	99,315	2,115	60,380	3,273	197,617	197,588	29	2.25	2.32
SE Asia	36,976	1,954	72,268	67,594	4,386	39,680	3,217	127,647	116,125	11,523	1.91	1.82
Asia (excluding Japan)	129,70	12,418	313,602	307,425	5,889	134,875	3,770	508,452	495.332	13,119	1.62	1.60
Developed world	4,280	4,075	17,440	17,376	64	4,412	5,107	22,534	20,135	2,399	0.86	0.49
Developing world	142,139	2,336	332,026	332,090	-64	150,629	3,609	543,616	546,016	-2,399	1.66	1.67
World (total)	146,419	2,378	349,466	349,466	-1	155,041	3,652	566,150	566,150	0	1.62	1.62

Table 2. Food availability, percentage, and number of malnourished children

Country/ region	Kcal/ capita/ day		Malnourished (%)		Malnourished (no.)	
	1990	2020	1990	2020	1990	2020
India	2,332	2,692	63.0	45.5	70,858	47,728
Pakistan	2,370	2,584	41.6	32.4	9,128	9,899
Bangladesh	1,978	2,170	65.8	52.8	11,963	11,456
Other South Asia	2,239	2,565	37.0	26.6	2,012	2,127
South Asia	2,297	2,640	58.5	41.37	95,811	72,939
Developed countries	3,353	3,532	-	-	-	-
Developing countries	2,500	2,821	34.3	25.4	18,440	155,729
World	2,773	2,895	-	-	-	-

period, the per cent malnourished children would decline from about 58 per cent to 41 per cent. However, the total number of malnourished children will decrease only moderately from 95,811 to 72,939, with nearly all the improvement in India (Table 2). The number of malnourished children in other South Asian countries will continue to be high during the next two decades (Agcaoili-Sambilla and Rosegrant 1996).

Constraints and Opportunities

South Asia accounts for about 39 per cent of land under rice cultivation in Asia. However, due to low average yields, its share in the world rice production is less. A major factor for low rice yields in South Asia is that only 42.3 per cent of the total rice grown area is irrigated, while the remaining 57.7 per cent area is rainfed, which suffers from uncertain weather conditions and periodic droughts, resulting in low and unstable yields (Table 3). Due to risk of crop failure, application of inputs, especially fertilizer, is low in rainfed ecosystems. In India, for example, the average rate of fertilizer applied to irrigated rice is ca.170 kgNPK/ha, as compared with 32 kg NPK/ha in rainfed environments.

Erratic rainfall leading to drought during the vegetative period in uplands, or prolonged submergence during the later stage in flood-prone areas are the major yield-reducing factors. Other constraints relate to the land and soil. Coastal salinity is a problem in Bangladesh and parts of India. Sodic soils are also prevalent in India and Pakistan. Cold injury, soil erosion, and micro-nutrient deficiencies, and blast are the major constraints of rice cultivation in hilly areas of Nepal, Bhutan, and India. Deficiency of P and K, and iron toxicity are common in Bhutan, Nepal, and Sri Lanka, while Zn deficiency is prevalent throughout the region. Lack of infrastructure, leading to low inputs

Table 3. Estimated harvested irrigated (IR), rainfed lowland (RL), upland (UL), and flood-prone (FP) rice areas in South Asia

Country	IR (% of Σ rice area)	IR rice area (000 ha)	RL (% of Σ rice area)	RL area (000 ha)	UL (% of Σ rice area)	UL area (000 ha)	FP (% of Σ rice area	FP area (000 ha)
Bangladesh	24.2	2480	43.1	4415	8.6	881	24.1	2469
Bhutan	50.0	13	3.8	1	3.8	1	42.3	11
India	43.8	18685	30.1	12852	14.6	6238	11.4	4874
Nepal	23.0	325	60.6	855	3.1	44	13.3	188
Pakistan	100.0	2097	0.0	0	0.0	0	0.0	0
Sri Lanka	77.0	610	14.9	118	6.9	54	1.1	9
Total (“)	42.3	24210	31.9	18241	12.6	7218	13.2	7552

Table 4. Crop loss due to rice insect pests, diseases, and weeds in various countries of South Asia

Pest (s)	Country	Crop loss
Stem borers	Bangladesh (outbreak year)	30-70%
	Bangladesh (non-outbreak year)	3-20%
	India	3-95%
Leafhoppers and planthoppers	Bangladesh (leafhoppers)	50-80%
	India (brown planthopper)	1-32%
Rice bug and gall midge (larvae)	India	10% loss in M ha
	India	12-35%
Blast	India	1% in 1960-61
Tungro	Bangladesh	40-60%
Baclerial blight	India	6-60%
Sheath blight	Sri Lanka	10% of rice tillers

and input-use efficiency, price fluctuation, and inefficient transfer of technologies are among other factors causing low yields in rainfed rice ecosystems of South Asia.

Rice crop losses due to insect pests, diseases, and weeds are estimated at 1 to 85 per cent (Table 4) (Rola and Widawsky 1998). Stem borers, brown planthopper, gundhi bug, leaffolders, green leafhopper, and gall midge are the major rice insect pests affecting large yield losses in South Asia. Bacterial leaf blight, blast, sheath blight, brown spot, and tungro are important diseases. With increases in wage rates, weeds are also becoming a factor constraining productivity and profitability in rice farming.

Throughout the region, the productivity in the irrigated ecosystem is quite high; 5 t/ha, compared with 2.3 t/ha for the rainfed lowland, 1.5 t/ha for flood-prone, and 1.1 t/ha for the uplands. Although the average rice yield in India is only 2.7 t/ha, compared with 5.8 t/ha in China, the average farm yield in states with dependable irrigation, such as Punjab, Tamil Nadu, and West Bengal, is 5.5 t/ ha (Hossain 1995). In India itself, the variation in rice yield is highly correlated with the proportion of area under irrigation. However, recent developments indicate that yield growth has started to decline. The rate of deceleration in yields is higher for countries with higher cropping intensities. In South Asian region, it is true for Pakistan, but not for India and Sri Lanka, which is attributed to the increase in irrigation infrastructure and policy reforms during 1980s. In Nepal and Bangladesh, the increase

Table 5. Extent of sub-ecosystems of shallow rainfed lowland rice in eastern India

State	Shallow rainfed lowland sub-ecosystems (ha x 10)				
	Drought prone	Drought and sub-mergence prone	Favorable	Submergence prone	Total
Assam	-	-	450	442	892
Bihar	948	750	-	-	1,698
Orissa	700	500	275	268	1,743
Madhya Pradesh	2,695	-	-	-	2,695
Uttar Pradesh	784	1,100	-	-	1,884
West Bengal	660	350	300	375	1,685
Total	5,787	2,700	1,025	1,085	10,597

in growth has come from crop intensification. Degradation in soil and water quality and insect pest build-up in intensive rice-rice and rice-wheat systems are the main factors for declining productivity (Pingali *et al*. 1997).

While raising yield levels and stability are the main concerns in rainfed rice ecosystems, reversing the trends of yield decline and sustainability are major issues in the irrigated rice ecosystem. Since rainfed ecosystem occupies a large area, even a small increase in productivity there will make perceptible gains in the overall production of rice in the region. Rice ecosystem analysis in eastern India has revealed that quite a sizeable rainfed lowland area is favorable wherein irrigated rice technologies can be fitted and productivity raised substantially (Table 5). Similarly, the analysis of drought and moisture availability in drought-prone area has indicated that by selecting appropriate varieties and adjusting planting time the risk could not only be averted but the average yield could also be increased in such areas (Table 6) (Singh *et al.* 1999).

Another opportunity exists in "boro" rice cultivation. Recent studies have shown that yield can be increased by growing "boro"' rice in and around deep-water areas (where surface or groundwater is not a limitation). Over the past two decades in Bangladesh, as the 'boro' season crop gave higher and more stable yields, the "boro" rice area has fast increased while area under deep-water rice declined. These results have led to fast spread and adoption of the technology in West Bengal and other neighboring states of India, resulting in increase in overall average yields. Exploitation of "boro" season for rice has thus emerged as one of the thrust areas for achieving rice production targets

Table 6. Moisture availability index (MAI) at different growth stages of medium and long duration rice varieties (values in parentheses indicate duration in weeks)

Crop stage	Medium duration varieties		Long duration varieties	
	Required MAI	Available MAI	Required MAI	Available MAI
Seedling	0.75 (3)	0.99	0.75 (4)	0.99
Vegetative	1.00 (5)	1.00	1.00 (6)	0.99
Reproductive	1.00 (6)	0.95	1.00 (7)	0.87
Maturity	0.75 (4)	0.60	0.75 (4)	0.62

in India (Siddiq 1999). But further research is needed to fully utilize the potential that it offers. Due to high profitability, the technology is spreading beyond the traditional areas of 'boro' rice cultivation, causing concerns for decline in underground water resource.

Little has been done about hill rice cultivation. Due to favourable agro-climatic conditions, the yields are generally high. However, developing rice varieties tolerant to cold, blast, and iron toxicity should further raise productivity in hilly areas.

Both India and Pakistan are the traditional exporters of Basmati rice. They account for ca. 1 M tonnes of annual export. Past few years, India has also started exporting 4 to 5 M tonnes of non-Basmati rices annually. Beside Basmati, India has a wealth of small- and medium-grain non-Basmati aromatic rices. However, due to neglect and increased adoption of high yielding varieties, most of these scented rices have disappeared (Singh and Singh 1998). Through proper resource utilization, not only these rices could be saved from extinction, but they could also become an invaluable source of income to rice farmers. Traditional rice farmers in hilly areas, where inputs of agro-chemicals are low, could be encouraged to grow organic rice. The potential for such rices also is quite high in Bangladesh. Rices with curative value for various ailments have potential for value addition and scope in modern food industry. Rice collections surveys made in the 1970s and 1980s in the Chattisgarh belt of Madhya Pradesh in India have led to the identification of several rice varieties of medicinal value (Siddiq 2002). Collection, inventorisation, and conservation of such valuable germplasm deserve due attention from the National Bureau of Plant Genetic Resources. The scope of such rices for export remains to be tapped.

Rice Research and Development: Impact on Production

The development of the modern semi-dwarf rice varieties and the use of increased inputs of fertilizer, irrigation, and crop protectants ushered in the first phase of the Green Revolution in rice growing countries (Fischer and Cordova 1998, Swaminathan 1999). Loans made available for development of irrigation infrastructure and conducive government policies led to widespread adoption of the new technology. The impact on food supply was immediate. This followed the development of seed multiplication infrastructure and seed distribution by extension systems, training of rice scientists and extension personnel in the way of the new generation of rice production technologies. With this also began the collection and conservation of rice genetic resources and their evaluation and utilization in rice breeding programmes.

The second phase of green revolution emphasised on stabilising yields by incorporating resistance to multiple pests and diseases and also reducing the growing period of rice cultivars. Other developments included introduction of farming systems methodology and mechanization of land preparation and threshing. The international sharing and testing of rice germplasm was also initiated and formalized.

These concerted efforts led to increased productivity, self-sufficiency, and even surpluses in many countries of South and Southeast Asia. In Asia as a whole, rough rice production shot up from 240 M tonnes in 1956 to 513 M tonnes in 1996, an increase of over 114 per cent over 30 years. This increase in production, which surpassed a population increase of 82 per cent in Asia during the same period, resulted in increased per capita availability of rice. The average rice yields in Asia increased from 2.1 t/ha in 1966 to 3.8 t/ha in 1996, an increase of ca. 2 per cent per year. The green revolution in rice was most dramatic and most successful in irrigated rice ecosystem. But large parts of South and Southeast Asia, where rainfed lowlands are the predominant rice ecosystems, have less benefited from rice revolution. Consequently, the yield growth has remained slow, at 1.4 per cent per year, much below the population growth rate.

More than three decades have passed since the advent of green revolution, and there are some concerns that the potential of the green revolution technology might have already been exhausted. A new green revolution is required so that at the prevailing price levels, the increased demand for rice by 50 per cent to 60 per cent over the next 30 years could be achieved. Accordingly, the new research targets focus on increasing yield per hectare by capturing the yield potential of existing cultivars and pushing the yield frontier up with tropical hybrids and new plant type, enhancing input use efficiency by increasing nutrient and water use efficiency, reducing labour costs, implementing integrated pest management, and sustaining resource base in the irrigated ecosystem.

Modern tools and procedures of genomics, cell culture, molecular biology, genetic engineering which, compared with traditional breeding methods, are more precise and rapid with high turnover are being deployed for new breakthroughs in yield potential. Significant strides have been made in hybrid rice research and hybrid rice farming has become a ground reality in India. The hybrid rice technology confers a 15 per cent yield advantage over the best inbred varieties. The technology is also spreading in Bangladesh. Efforts are underway to enhance the heteroic level of the tropical hybrids to make hybrid rice cultivation more profitable. Possible development of apomictic hybrids, which would avoid the need for F_1 seed production, would make the technology even handy for the poor resource farmers. Similarly, the prototypes of the new plant type are already at the field-testing stage and are likely to reach farmers' fields soon. These genotypes promise about 20 to 25 per cent increase in yields (Khush 1995). Linking heterosis to still more desirable traits, such as insect and disease resistance or tolerance to abiotic stresses, such as salinity and alkalinity, can help the crop perform even better and substantially offset the cost of production.

For impact on rainfed rice, the research targets are focusing on developing tolerance to abiotic stresses, maintaining natural resilience of ecosystem to pests, supporting direct seeding methods for crop establishment, incorporating micro-nutrients in rice, and improving grain quality. If the rice research could succeed in incorporating traits that help modern varieties withstand abiotic stresses and maintain high yield, then such varieties will be adopted readily and more extensively in the unfavorable ecosystem because the risk in cultivation will be reduced. Farmers will have the incentive to apply chemical fertilizers at optimum levels, which will further improve rice yields.

Modern biotechnology tools can enhance these efforts by increasing the efficiency of conventional breeding and by using genetic engineering to bring non-rice or alien genes into the rice gene pool (Bennett 1995), enabling selection of genetically complex traits with high precision and monitoring of changing virulence in pests. Some of the promising research programmes in progress are engineering resistance to stem borer, leaffolder, bacterial leaf blight, sheath blight, and rice tungro virus, and improving nutritive quality by increasing ß-carotene (vitamin A) and protein content using novel genes from near and distantly related life forms. However, the commercial application of biotechnology products in general may still be somewhat problematic. A major policy issue is the regulatory climate governing the release of genetically engineered products or generically modified crops to ensure public health and environmental integrity. The countries in South Asia, including India, have yet to equip with necessary regulatory mechanisms to import, test, and use such materials. Intellectual property protection and plant breeder's right may further delay easy access to materials developed through the use of biotechnology tools.

Although concerted efforts to improve rice production in rainfed ecosystems began only about a decade ago, the progress is quite encouraging. Two major developments that took place in early 1990s, greatly spurred research of rainfed ecosystems. IRRI organized the research programme according to the rice ecosystems that ensured adequate support and opportunities for rainfed rice. The rice research consortia that also began operating early 90s, brought together the resources from NARS in South Asia and IRRI to solve the problems of individual rice ecosystem in a concerted and systematic way by sharing resources and responsibilities. Table 7 gives participatory sharing of responsibilities for conducting strategic research under the Rainfed Lowland Research Consortium. The results are already there to show the impact of these complementary efforts. With lager and better trained scientific staff, deeper and broader knowledge of rice production problems and constraints, increased emphasis on applied as well as strategic research issues, and greater motivation of scientists, the Asian NARS are contributing substantially to the development of technologies that will increase and sustain higher production of rice in their own countries and in other rice growing countries of the world.

Some Emerging Concerns

By 2025, 50 per cent to 60 per cent more rice needs to be produced. However, the land, labour, and water, the basic resources responsible for production are getting increasingly scarce and fatigued and are in need of efficiency gain. Pollution of soil, water, air, bio-mass, and

Table 7. Key sites and their research focus of the Rainfed Lowland Rice Research Consortium in South Asia

Country	Key site	Institute/ region	Research focus/ expertise
Bangladesh	Rajshahi	Bangladesh Rice Research Institute (regional station)	Moderate drought, photoperiod sensitivity
India	Cuttack, Orissa	Central Rice Research Institute	Agricultural Engineering and socioeconomics
	Polba, Chinsurah West Bengal	Expt. Station, Polba and Rice Research Station, Chinsurah	Stagnant flooding
	Faizabad, Masodha	Expt Station, N. D. Agri-cultural University	Salinity/shallow flash flooding
Indonesia	Jakenan, Central Java	Jakenan Expt. Station (under Sukamandi Research Institute for Food Crops)	Dry direct seeding ('gogo rancah'), potassium deficiency
Philippines	Batac, Ilocos Norte	Philippines Rice Research Institute	Long-term sustainability of production systems
	Tarlac, Pangasinan		Rainwater conservation, nutrient, tillage properties
Sri Lanka	Bombuwela	Regional Agric. Research Centre	Iron toxicity, brown spot
Thailand	Ubon	Rice Research Centre, Ubon	Severe drought/ poor soil physical problems, low soil fertility, and phosphorus deficiency, rice blast, weeds

production of greenhouse gases is also being linked to inefficient use of agro-chemicals and agri-inputs. There is thus an urgent need for a thorough assessment of the opportunities for increasing land productivity, including crop diversification. Similarly, as the opportunity cost of family labour rises, given alternative employment opportunities, there is need for labour-saving technologies. Growing water scarcity for irrigated rice ecosystem is another serious challenge for which, while technological options, such as recycling, exist, but little has been done in respect of complementary policies. At present, more than 5 tonnes of water is needed to produce a kilogram of rice.

The irrigated rice environments not only face increased competition for water, but also face reduced water supplies due to system degradation and reduced investments in infrastructure development. In South Asia, the growth rate in irrigated area has dropped from 2.8 per cent during 1975-80 to 0.1 per cent during 1985-88 period (Rosegrant and Swendsen 1992). It is absolutely necessary that technologies that are promoted must sustain rather than degrade the long-term productivity of the resource base.

Since the beginning of 1990s, unit production costs are beginning to rise and rice farmers are facing declining profits. The stagnant yield frontiers and diminishing returns to further intensification are the primary reasons for the current reversal in rice profitability. Further, rapid withdrawal of labour, division of land to other uses, increased competition for water, and withdrawal of subsidies on agricultural inputs have all led to increasing the cost of rice production. In the absence of shift in yield frontiers for rice and/or a substantial improvement in input use efficiencies, the profitability of rice production in Asia may revert to the pre-green revolution era.

The South Asian countries made a great leap in food production over the last three decades. The technological innovations complemented by public investments and policies that promoted intensive rice production systems helped bring about the change in food supply. However, there is a growing sense of complacency about the current and future food supplies in this region. Lack of concern is seen in declining national budgetary allocation for maintaining existing rice infrastructure, including irrigation, reduced bilateral and multilateral donor support for expanding irrigation, a deliberate policy shift towards diversification out of rice, and a substantial cutback in research funding at both national and international levels. Emphasis has shifted to natural resource management and environmental sustainability. However, there are signs that this complacency is not warranted, as greater challenges for producing extra rice in future exist.

Although currently the countries of South Asia are pursuing the policies for achieving self-sufficiency in rice production, it is anticipated that over the next two decades, some of them may have to go for rice import to make up for further domestic shortfalls. Pingali *et al.* (1997) have indicated that domestic shortfalls could occur due to: (i) continued and unabated population growth, (ii) rapid economic growth in some countries that will make the maintenance of self-sufficiency unprofitable, and (iii) trade liberalization and agreements that could lead to Asian food sector becoming more open to international competition. While the short-term effects of GATT agreement could be modest, the long-term effects could be substantial (Pingali 1995). Small countries that are self-sufficient now in rice, may find it profitable to import at least a part of their rice requirements in exchange of diverging production resources to more remunerative activities. However, for countries with large rice-eating population and low-income, such as India and Bangladesh, achieving food security through imports may not be possible due to high volume involved and foreign exchange constraints. For these countries, increasing productivity on rice lands should remain a top priority.

Among the technological options, hybrid rice is a commercially viable technology with 15 per cent yield advantage over the best inbred varieties. India, first among the countries outside China to develop and commercialise hybrid rice technology, however, has yet to take full advantage at the desired level. As against one million hectares targeted for 2000, not even one-fifth could so far be planted to hybrid rice (Siddiq 2002). Inability to meet the seed demand, a factor that contributed to slow pace of adoption, would have to be overcome. Also, hybrid seed quality would have to be ensured to avoid inconsistent yield performance.

Free exchange of rice germplasm provided unlimited resources for rice improvement programmes and sharing of improved materials among the rice growing countries. However, due to imposition of the intellectual property rights and other WTO requirements, the restriction on germplasm exchange is fast growing. Under these circumstances, countries with poor genetic resource base and not-so-well developed research set-up, such as Nepal and Bhutan, would face difficulties in accessing improved rice germplasm. The countries in South Asia could, however, develop some collaborative mechanisms to ensure exchange and use of rice germplasm among themselves without affecting each other's interest and sovereignty right. Adequate increase in budgetary support for rice research and development is long overdue in countries in South and Southeast Asia so that it becomes comparable to that in developed countries.

The seed-fertilizer technology of green revolution era was simple and its impact was easily visible. The new technology which deals with complexity of the natural resource management, input use efficiency, and sustainability needs clear understanding and better skills for its transfer and adoption. Its impact also is slow, but with long-term effects. The challenge for the research system is in finding efficient and cost-effective methods for transferring knowledge-intensive crop management technologies to farmers. The ultimate goal is to have farmers who are capable of deriving the appropriate recommendations for each farmer's field using 'if-the' type analysis. The current practice of providing blanket recommedations of fertilizer application to farmers over large areas is no longer a valid mode of operation for extension workers. To reduce knowledge gap, the extension services in future would have to transfer knowledge and provide decision-making options rather than straight input use recommendations. The extension technicians and farmers, therefore would have to be well trained, and the scientists more responsive to convince farmers of the importance of the technologies and how they work. Information technology could play an important role in rice production and natural resource management. It would require upgrading of educational curricula of agricultural schools and colleges. India, being a leader in the field of information technology, could gain substantially by introducing precision farming approaches at farmer level.

The application of modern technologies, such as biotechnology, remote sensing, meteorological information for medium and long-term forecasts, crop modelling, geographic information system, etc., requires trained personnel and state of the art research facilities. Except, perhaps, India, few other countries in South Asia have the required capacity to absorb and utilize these technologies for the benefit of rice production. Working closely with advanced laboratories or through the International Rice Research Institute could therefore be advantageous. It would be detrimental to agricultural economy as a whole, if these countries are left behind in harnessing the benefits of these advanced technologies in solving some of the present problems. Also substantial policy reforms ought to be in place before the fruits of biotechnology would become available to the rice farmers in South Asia.

A holistic food security policy need not be anti-environment; it can actually contribute to long-term environmental sustainability. Rational food production systems that improve the efficacy of inputs and resource use, help conserve the natural resource base rather than threaten it.

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