Technological Progress for Sustaining Food-Population Balance: Achievement and Challenges

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I. Introduction

Food is the most basic human need. At low levels of income, the utmost concern for the human being is to meet the energy needs to overcome hunger. Cereals provide the cheapest source of energy. The per capita intake of cereals as human food is often high at low levels of income, and increase further with rising income, but starts declining when the basic energy needs are met. At middle income level people can afford to have a more diversified diet that provides balanced nutrition with adequate consumption of vegetables, fish and livestock products that are rich in, vitamins and micronutrients. But as the demand for livestock products increases with economic prosperity, so does the indirect demand for some cereals such as maize and coarse grains that are used as livestock feed. The decline in per capita consumption of cereals as human food is over-compensated by the increase in per capita demand for cereals as livestock feed, since the amount of cereals needed to have the same level of calories from livestock product is many times higher than when it is used as direct human food. The per capita consumption of cereals increases monotonically with the growth of incomes.

The most important factor determining the demand for cereals is the population growth. The world population has more than doubled since the 1950s when science-based innovation in health care and sanitation contributed to drastic reduction in the mortality rate and thereby rapidly accelerated population growth and has now reached 6.4 billion. The world population may increase another three billion before stabilizing in 2100. Over the next quarter century the world population is projected to increase by 1.95 billion; mostly in the developing countries and in the regions where poverty and hunger is widespread such as in Sub-Saharan Africa and South Asia. In these regions the per capita cereal consumption is still about half of that in the developed countries.

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The developed countries may not need further increase in cereal production as most of them have reached a stationary population, and some have started experiencing an absolute decline.[1] The per capita consumption of cereals have also started declining because of sluggish domestic demand for livestock production and growing consumer's preference for low calorie diets with dominance of vegetables and fruits. The situation in the developing countries is however opposite because of the continuing high growth of population. It is expected that the total cereal consumption will continue to increase, despite a moderate decline in the per capita consumption of cereals as human food, due to population growth and the growing demand for livestock products (Rosegrant et al, 1995; Sombilla et al, 2002). It is the poverty-stricken regions such as sub-Saharan Africa and South Asia where per capita consumption is expected to increase with reduction in poverty, the population is also growing fast.

The potential for increasing the supply of food through expanding the land frontier has long been exhausted particularly in the densely settled countries in Asia where 60 percent of the World's population live. With the increase in the pressure of the population on limited natural resources, land prices have continued to increase relative to other factors of production. The land-saving technical change that increases the crop yield (productivity per unit of land per season) has been the dominant source for maintaining the food-population balance. However, the potential for increased land productivity created by the dramatic technological breakthroughs in the late 1960s for the irrigated and favorable rainfed environments have almost been exhausted. Since the late 1980s, there has been a drastic slow down of yield growth for all cereal crop (Table 1). The growth in yield has decelerated from 2.1 percent to 1.2 percent per year for rice, from 2.5 to 1.1 percent for wheat, and 2.0 to 1.8 percent for maize. After reaching the bottom in 2000, prices of cereals have been rising consistently leading to deletion of stocks which reached below the critical level. Again concerns are raised regarding the world's ability to maintain the food population-balance, as during the 1960s and the early 1990s (Padock and Padock, 1967; Brown 1995; Huang et al 2002; Brown 2006).

[1] The situation may change if petroleum prices continue to increase. The demand for maize may increase rapidly due its use as raw materials in ethanol production which is a substitute for petroleum. Brown (2006) reports that the use of grain for fuel is growing by over 20 percent per year compared to one percent per year growth for use as food and feed.

Against the backdrop of this development, this paper reviews the induced innovation that shifted the technology frontier, analyzes its contribution to increase in crop production through adoption of land-saving technologies, and outlines the challenge ahead for research to sustain the food-population balance. The discussion is limited to the rice crop, the dominant food staple in the developing countries.

II. Institutional Innovation for Land-saving Technologies

The theory of induced innovation (Hicks, 1932; Hayami and Ruttan 1985; Hayami, 1997) states that changes in resource endowments induce changes in technology. As the endowment of one factor becomes abundant relative to other factors, a change in technology is induced towards using the abundant factors for saving the scarce factor for given relative factor prices. The green revolution is considered an innovation in agricultural production technology induced by population pressure on limited land resources. Owing to the availability to developing economies of scientific knowledge accumulated in industrialized countries, an institutional innovation was induced in the form of a public-supported agricultural research system to develop technologies that helped save the increasingly scarce land with higher use of the relatively more abundant labor and capital.

Technological innovations are carried out mainly by large farms with research and development capacities in an effort to reduce production costs by substituting relatively more abundant resources and thereby cheaper resources for scarcer and hence expensive resources. The crop breeding programs ultimately supported by farmers by purchasing improved seeds at higher prices, had by early 1950s produced several generations of modern crop varieties in developed countries who adoption led to rapid increase in land productivity.

When the population pressure on limited land resources accelerated in the developing countries, the need for development of such land-saving technological progress was felt. But it became clear that private sector farms were unlikely to make significant investments in crop improvement research targeted at the major crops grown in the developing countries. Since there was no effective intellectual property protection in crop varieties at that time, there was no incentive for private sector to invest in such research.

As agriculture was strongly constrained by environmental conditions, it was difficult to transfer advance technologies developed in the industrialized countries for their temperate zone to the tropical and sub-tropical zone in the developing countries. However with appropriate adaptive research, agricultural technology transfers across different environments could be possible.

The institutional response to these realities was to develop international agricultural research centers (IARCs) supported by international donors (Hayami and Ruttan, 1985; Evenson and Golin, 2003). This system eventually led to development of a formal structure known as the Consultative Group for International Agricultural Research (CGIAR) that has a mandate among others to develop improved technologies for the major food crops in the developing countries. The IARCs that the CGIAR system supports, work with national agricultural research systems (NARS) in developing countries, to undertake and support crop breeding and genetic improvement research, and to develop options for efficient and sustainable management of resources.

Three different IARCs have been involved in developing improved agricultural technologies for rice, the dominant food crop in developing countries.

The International Rice Research Institute (IRRI) established in 1960 in the Philippines made the first breakthrough in 1966 in developing a semi-dwarf rice variety (IR8) that saves land by using additional chemical fertilizers and labor, provided farmers have good water control in their fields (the "seed-fertilizer-water" technology). The new variety gave two to three times higher yield (output per unit of land per season) compared to traditional varieties grown by farmers (Barker et al, 1984). Built on that success, a successive generations of improved varieties and breeding materials (germplasm) were developed to address other concerns such as resistance to pest pressures, reducing the duration of crop maturity, and improving grain quality (Khush, 1994). As national programs grew in strength, IRRI abandoned the practice of releasing varieties directly and instead shifted to the strategy of supplying germplasm and elite breeding lines to national programs for evaluation, selection and use. This role was facilitated by an international network for germplasm exchange that provides NARS breeders ready access to breeding materials (Evenson and Golin, 1997).

Almost 90 percent of the rice area is located in Asia, with 133 million ha out of 155 million ha of rice land. But rice is a significant crop in a number of countries in Africa and Latin America. The non-Asian countries received improved rice varieties through INGER. But the Asian rice varieties were not particularly well adapted to Latin America or Africa (Chaudhary et al. 1999).

International Center for Tropical Agriculture (CIAT) located in Colombia, established a rice breeding program that undertook adaptive breeding to develop varieties combining improved germplasm from Asia with indigenous varieties grown in Latin America. Brazil also has an advanced rice breeding program for developing varieties for the uplands and for the temperate climate in South America. These institutions have made progress in developing appropriate rice varieties for South America reducing the dependence on IRRI for improved germplasm.

Although many improved germplasm from Asia were evaluated under African condition, few are adopted by farmers due to difficult growing conditions. The West Africa Rice Development Association (WARDA) established for adaptive research on rice in Africa was not effective until it was established as a center capable of doing its own breeding in the 1980s. By mid-1990s, WARDA produced a range of improved germplasm by crossing improved Asian varieties with locally adapted and multiple stress-resistant African landraces. The improved germplasm has been dubbed as New Rice for Africa (NERICA). The NERICA appears to offer a rich source of genetic resistance to drought, weed competition, blast, virus diseases and soil acidity and iron toxicity (Dingkuhn et al, 1998; Diagne, 2006). The NERICA materials promise to be particularly well suited to low-input conditions of rainfed rice farming in Africa.

A recent study conducted under the leadership of Evenson and Golin (2003) shows the in Asia production of improved varieties increased substantially in the 1980s compared 1970s, but declined in the 1990s. For Latin America, the production of improved varieties was low in the early period, but has accelerated in the 1990s. For Africa, the production has been negligible. The adoption of modern varieties has reached over 70 percent in Asia, 55 percent in Latin America, but less than 20 percent in Africa.

The estimate of the net gains from the adoption of modern for selected Asian countries can be seen from Table 2. The rice yield increase by about 2.1 t/ha as farmers adopt modern varieties in place of traditional varieties. But the adoption entails additional cost on account of fertilizers, irrigation charges, labor and pesticides. This additional cost is estimated at 1.16 t/ha in rice equivalents. The net yield gain is estimated at 0.94 t/ha, about 41 percent over the yield of traditional varieties. Evenson (2003) estimates that the total factor productivity growth for the 1965-95 period was 1.2 percent per year; it was 1.5 percent per year for the first two decades (the Green Revolution period) and but has decelerated to 0.6 percent during 1985-95 period. Several other studies have indicated a decline in total factor productivity growth in rice cultivation at the country level (Kumar and Rosegrant, 1994; Estudillo and Otsuka 2006; Janaiah et al. 2006).

III. Achievements in technological progress

This section assesses achievements in technological progress for major rice growing countries by generating information on growth in rice yield and area with time series data for the period 1970 to 2005. The analysis has been conducted for all countries with a rice area of over 100,000 ha. India and China account for about 50 percent of the global rice area. China has a fairly homogeneous production environment, and the difference in yield level across regions is marginal. India however has diverse agro-ecological conditions across states with large variations in yield. So, for India, the analysis has been conducted at the state level.

To assess whether technological progress has decelerated in the recent period, we have divided the period in two phases, 1970-90 (the Green Revolution period) and the 1990-2005 (the post Green Revolution period), and estimated the growth rates for the two periods. The following trend equation was fitted to estimate the growth rates:

$$LnY= a+ bD + c T + d (D*T) +u$$

Where Ln is natural logarithm; Y is the variable for which the rate of growth is estimated; D is the dummy variable taking value 1 for the 1990-2005 period and 0 otherwise; T is the time trend (taking value 1 starting from 1970). The rate of growth for 1970-90 is given by the value of the estimated parameter “c” and that for the 1990-2005 period is given (c+d). The negative value of the parameter “d” indicates that the growth has decelerated during 1990-2005 compared to 1970-90 period. The trend has been estimated both for yield as well for area to see the contribution of yield to the growth in output. The trend equations and the growth rates are reported in Tables 4 to 7.

Out of 43 countries under study, the growth in yield decelerated in 19 countries as indicated by the negative coefficient of the interaction variable in the trend equations (Table 4). Among nine of them the value of the coefficient is significantly negative at five percent level. The three giant economies of Asia- India, China and Indonesia that account for 60 percent of the global rice area are among them. For China, the yield growth has decelerated from 3.1 percent during 1970-90 to only 0.7 percent during 1990-2005; For Indonesia the growth has declined even faster from 3.3 to 0.3 percent. In these countries, rice is grown mostly under irrigated conditions, the adoption of modern varieties is almost complete, and the yield has reached high levels in the irrigated environment. For India, the decline has been moderate from 2.3 to 1.0 percent. The drastic slow down in the growth in rice yield and production in the world during 1990-05 was mainly on account of these three countries. The other countries experiencing deceleration in yield growth are Myanmar, Philippines, Iran, Dominican Republic, and Nigeria. In Iran and Dominican Republic rice is grown under irrigated conditions, and the decline in growth may indicate reaching plateau in the adoption of existing technologies. Myanmar, Philippines and Nigeria have expanded substantial the area under rice in the later period (Table 5). The decline in yield growth may indicate that such expansion has been taking place on marginal lands. At the other end, nine countries experienced significant acceleration in yield growth during the recent period. These countries are Bangladesh, Brazil, Cambodia, Egypt, Guinea, Madagascar, Mozambique, Nepal, Pakistan, Peru, Spain and Thailand. In all these countries (except in Peru and Brazil) rice is grown under predominantly rainfed conditions, and the growth in yield was low in the earlier period. The increase in yield growth in these countries is a reflection of the expansion in the coverage of irrigation during the later period. The growth in rice yield and its contribution to production at the broad regional levels can be seen from Table 3. The growth in rice production was respectable during 1970-90; at more that 2.2 percent per year for all the regions, which eased the pressure of expansion of cultivation to marginal areas due to population growth. There was very little increase in the expansion of rice area during this period.[5] The yield growth during 1990-2005 has decelerated in all regions, except in Latin America.

The decline in the growth in yield has been fast in East Asia, from 2.7 percent per year during 1970-90 to only 0.6 percent during 1990-2005. The growth in yield has declined in all four countries in the region mainly in response to a reduction in the growth of per capita consumption and of population. This development started much earlier in Japan and South Korea. China has experienced the same trend in the 1990s. Along with the deceleration in yield growth, the region has also experienced reduction in the area under rice cultivation. During 1990-2005, rice harvested area declined by 2.1 percent per year in Japan, 1.1 percent in South Korea, and 1.0 percent in China.

Southeast Asia is the home of the two major rice exporters, Thailand and Vietnam as well as the two major rice importing countries in the world- Indonesia and the Philippines. The yield growth was relatively fast in Indonesia and the Philippines in the early period, as irrigation infrastructure was already developed that facilitated rapid technological progress. With no further investment in the expansion of irrigation in the later period, and the degradation of the existing irrigation system, the yield growth tapered off. With continuing population growth both have reverted back from self sufficiency to import dependence. Only Vietnam was able to maintain the growth in both the rice harvested area and yield through development and diffusion of high-yielding shorter-maturity rice varieties. Vietnam has almost exhausted its capacity for increasing rice production and has started adopting a policy of agricultural diversification to boost farmers' incomes. Thailand, Myanmar, and Cambodia have considerable excess capacity for increasing rice production. The rice yield remains at a low level and additional land could be brought under cultivation with expansion of irrigation, particularly through increasing area under the second rice crop in the dry season. Thailand has continued to increase exports even when rice prices remained low in the world market. Farmers have maintained a low cost of production despite increasing wage rates through consolidation of farm holdings and mechanization of agricultural operations.

[5] In many countries the small growth in rice area was mainly due to expansion of irrigation which allowed farmers a dry season rice crop after harvesting the monsoon season rice. The expansion of rice harvested area is the result of the increase in cropping intensity with rice.

In South Asia, India and Bangladesh account for a third of the global rice area with 53 million ha of rice land. In Eastern India, Nepal and Bangladesh, the dominant rice production system is rainfed, while in the northern and southern India and in Sri Lanka and Pakistan rice is grown mostly under irrigated conditions. In Pakistan rice is a commercial crop and the technological progress responds to favorable prices in the world market. India continues to expand rice production through providing subsidies in irrigation and chemical fertilizers and a minimum support price for farmers. The trend analysis at the state level however shows that out of 14 states for which rice area of over 100,000 ha, the yield growth has declined in the recent period in 12 states (Table 6). The decline in growth is statistically significant in Punjab, Haryana, Tamil Nadu, Andra Pradesh and Uttar Pradesh. In these states rice is cultivated mainly under irrigated conditions, and the yield has reached high levels. With technological progress approaching the plateau, the stagnation in yield is setting off. In the rainfed system in Eastern India and Nepal, the technological progress has been continuing, but occasional droughts and floods due to erratic monsoons disrupts the productivity growth. Bangladesh has substantially reduced the yield gap in the irrigated ecosystem over the last decade with rapid private sector investment in small scale irrigation equipment for pumping ground water. The productivity growth may slow down in the future because of the plateau in yield for the dry season rice crop (boro) and slow technological progress in the large flood-prone and salinity-prone coastal areas. Sri Lanka made yield gains through technological progress in the earlier period, but recent progress has been hampered by labor scarcity and high wage rates compared to other South Asian countries. In sub-Saharan Africa the growth in yield was limited during the earlier period, and turned negative during the later period. The production growth was more than 3.0 percent to meet the rapid growth in demand emanating from population growth and the increase in per capita consumption. The demand was met mainly through the expansion of rice area and imports from Asia.[3] During 1990-05, rice area has expanded at over 2.0 percent per year in Ghana, Liberia, Mozambique, and Nigeria (Table 5). With continued expansion of rice area to marginal land, the yield started declining in absolute terms.

[3] About half of the total rice consumption in Africa is met through imports. Africa now accounts for a third of the global rice market.

In Latin America, Brazil is the dominant rice producers accounting for over 80 percent of the total rice area in the region. The growth in rice yield was low in most countries of the region during the early period indicating a late start in technological progress. The yield growth has accelerated in the later period from the initial low base. The yield growth has increased from 1.6 percent per year during 1970-90 to 3.5 percent per year during 1990-05 for Brazil. The numbers are 1.1 and 2.0 percent respectively for Peru, 1.3 and 2.5 percent for Uruguay, 1.5 and 2.2 percent for Columbia, and 3.2 and 3.3 percent for Cuba. Only in Dominican Republic the yield growth has slackened as it expanded the growth in rice area from 1.8 percent per year during 1970-90 to 2.7 percent during 1990-2005. In Brazil the increase in the growth in yield reflects the reduction in area under upland rice in the central Amazon region, and the expansion of area under irrigated ecosystem in the South. In Brazil, rice area increased by 0.3 percent per year during 1970-90 but drastically reduced to a negative 1.9 percent during 1990-2005 (Table 5).

The above review of the growth rice area and yield at the country level supports the following major points. a) The technological progress proceeded early in countries which already had a well-developed irrigation infrastructure. b) The countries with rainfed ecologies picked up the technologies in the later period with gradual expansion of irrigation through government or private sector investment. c) Attempts to increase rice production through area expansion without recourse to adoption of improved technologies have led to further decline in rice yield from an already existing low level. d) The yield stagnation sets in (at a level of about 6.0 t/ha) as the technological progress reaches the plateau. It suggests that there has been no further land-saving technological change after the first innovation.[4] e) The yield gap between the irrigated and the rainfed ecosystem still remains high. It indicated that appropriate land-saving technologies have not yet been developed. The low yield in the rainfed system, limited scope for further expansion of irrigated area due to growing water scarcity (Seckler et al; 1998; Rosegrant and Pingali, 1994: Barker et al, 1999), and the exhaustion of technological progress in the

[4] A number of studies led by Otsuka and Kalirajan show that successive generation of modern rice varieties developed in the public sector research system in Asia did not contribute to further increase in technical efficiency over and above the gains made from the replacement of traditional varieties by the first generation modern varieties. The later generations of modern varieties incorporated resistance of rice plants to pest pressures to reduce the yield losses from pests, and reduced the crop maturity period for facilitating crop intensification and diversification (Otsuka and Kalirajan, 2006; Estudillo and Otsuka, 2006; Ut and Kajisa, 2006; Hossain et al 2006).

irrigated ecosystem raise concern regarding our ability to maintain food-population balance in future.

IV. Challenges Ahead

Because of limited amount of land and water in many parts of the world, and the growing scarcity of these resources with continued increase in population, the only way to increase the food production is to develop technologies that continuously increase output per unit of land and water. The community of rice scientists faces the following challenges in sustaining the food population balance: a) raising the yield frontier of rice which has not increased since the first generation of rice varieties were released, b) sustaining the current high yields in the intensively cultivated irrigated systems, and c) closing the yield gap between the irrigated and rainfed systems (Scobie et al 1993; Hossain and Fisher 1995)..

Shifting the yield potential for the irrigated system

The yield potential of current high-yielding varieties developed for the tropics is 10 t/ha for the dry season and 6.5 t/ha for the wet season. Since the release of IR8 in 1966, only marginal increases have occurred in the yield potential of rice.[6] Since then scientists have largely focused on incorporating insect and disease resistance into improved varieties, shortening the growth duration of the crop, and on improvements in grain quality (Khush, 1995).

IRRI scientists proposed modifications to present high-yielding semi-dwarf plant architecture and developed a "new plant type" for direct seeded crop establishment. Compared with current modern varieties, the new plant type will have fewer tillers, but those tillers will have longer panicles bearing more grains, thick and erect leaves for higher photosynthesis efficiency, and sturdier stems and deeper roots to support the increased grain weight. The grain-biomass ratio for the new plant type will be increased from 50 percent for the present improved varieties to 55 to 60 percent in the new plant type. The new plant type will shift the yield potential by another 25 percent. The new

[6] The growth duration of modern rice varieties has however been reduced from 140 days to 100-110 days with no penalty in yield. It indicates that yield per day has increased greatly. To the extent that the shorter maturity varieties have facilitated growing more that one rice crop during the year, the output per unit of land per year has also increased.

plant types have already been developed and shared with NARS, who are currently using them in their breeding programs. Two varieties have already been released in China, which contain the new plant type material.

A relatively more mature technology that shifts the yield frontier is hybrid rice. Hybrids, the progeny of distinct parents, create increased vigor and yield through heterosis. Hybrid rice has been grown in China since 1976 and on average has a yield gain of 15 to 20 percent over conventional high yielding varieties (Virmani et al 1993). New experimental evidence indicates the possibility of further enhancing the level of heterosis by crossing indica with tropical japonica rice varieties. Several hybrid rice varieties have already been released by NARS in the tropics, but the expansion of area has been slow because of limited profitability gains emanating from high seed costs and lower quality grains (Janaiah and Hossain, 2003). These problems is expected to be overcome with further breeding, as similar problems were experienced in China during the initial period of extension of hybrid rice (Lin, 1994).

Rice is a plant with C3 photosynthesis, which has lower photosynthetic rate than the C4 plants, such as maize and sorghum. Scientists have been examining the possibility of converting rice into a C4 plant. Recently, several genes for C4 pathway have been isolated, and efforts are underway to introduce these genes into rice through transformation.

Sustaining the current yields in irrigated systems

The irrigated systems now contribute to over 70 percent of rice production. Maintaining this contribution through achieving yield stability is a major challenge. The stability of rice production is constantly threatened by chronic pest infestations and epidemic outbreaks. Major genes conferring resistance against diseases and insect pests have been widely used in rice improvement program. Useful genes have been transferred from wild species to rice through wide hybridization program. The successful isolation of many resistance genes and insecticidal proteins has further enhanced the ability of the rice breeders to incorporate these genes into rice varieties. Recent advances in dissection of defense pathways in plants have revealed novel genes that may lead to a rational design of broad-spectrum resistance. However, rapid erosion of host resistance due to adaptation by pathogens and insects remains a primary concern in sustaining high yields. Future challenge will require not only the accumulation of effective resistant genes, but also an understanding of the consequences of the deployment of the genes in the field.

Rice is a heavy water using crop. As water increasingly becomes a scarce resource, action will have to be taken to make better use of existing water supplies, if wetland rice cultivation is to be sustained. Options for more efficient management of water in rice farming will have to be developed and appropriate water pricing policies developed to induce farmers to adopt these technologies. IRRI scientists are also working to develop improved varieties (aerobic rice) that can be grown with less water with much yield penalty.

Traditionally, farmers keep the field inundated with water to reduce weed competition. Research on increasing water use efficiency therefore will have to take into account weed control. The traditional practice of flooding, puddling and transplanting is being replaced by direct seeding of rice in response to growing shortage of agricultural labor (Zeigler and Puckridge, 1995). New ways of controlling weeds are required because of changes in weed flora, herbicide resistance and growing public concern about the harmful effects of agro-chemicals on human health and environment.

Reducing yield gaps for unfavorable rainfed environments

Almost half of the global rice area 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 plant 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.

Many traditional varieties have developed traits through centuries of evolution that enable them to withstand the submergence and drought stresses. Rice scientists have so far had limited success in identifying these traits and incorporating them into high-yielding varieties. The currently available modern varieties may do well in normal years, but perform poorly compared to traditional varieties, if there is prolonged drought and sudden submergence due to an erratic monsoon. So where the rainfall is unreliable, farmer still grows traditional varieties or use inputs into sub-optimal amounts when adopt modern varieties, which are the main factors behind the low yield and the large yield gap in rainfed rice cultivation compared to the irrigated system.

Biotechnology, and the use of gene mapping and marker aided selection have much to offer for the development of varieties tolerant to submergence, drought and problem soils (Bennett, 1995). Already a gene for submergence tolerance (Sub1) has been incorporated into Swarna, a widely grown variety in South Asia, which is being validated by NARS through farmer-participatory experiments. The improved germplasm can withstand submergence for 10-12 days. Another gene for salt-tolerance (Saltol) has been fine mapped, and has been introgressed with maker assisted breeding to develop improved lines. Despite substantial efforts developing tolerance to droughts in high-yielding varieties has remained illusive. However, minor genes for various sub-component traits of drought tolerance in rice have been mapped, and this information is being utilized to develop improved varieties with drought tolerance.

If rice research succeeds in incorporating modern traits that help withstand climatic and soil related stresses, modern varieties will be adopted more extensively in the unfavorable ecosystems. The yield stability of the varieties will reduce risk in rice cultivation, thereby providing incentives to farmers to adopt modern varieties and to apply inputs in optimal amounts that will, in turn, lead to further yield increases.

V. Conclusion

The most promising avenue to sustaining the food security in the face of growing pressure of population on limited land resources is continuous growth in land productivity through development and diffusion of land-saving technology. Since agricultural technologies are difficult to transfer from developed to developing countries due to different agro-ecological situations, an institutional innovation was induced in the 1960s to develop such technologies through establishment of international and national research institutes in the public sector. For rice, the dominant food staple in developing countries, successive generations of improved varieties were developed that substantially increased the rice yield with additional use of chemical fertilizers, labor and irrigation.

The contribution to yield growth net of the additional cost of inputs was about 1.0 t/ha, about 40 percent of the yield in traditional varieties. The progress in the adoption of the technology contributed to a yield growth to meet the growing the demand for food.

The growth in yield has however slowed down substantially since the early 1990s due to technological progress reaching its limit in the irrigated ecosystem, limited expansion of irrigated area due to growing scarcity of water, and a large yield gap in the rainfed system due to non-availability of technologies suitable for the unfavorable environments. The development raises concern regarding the world's ability to meet the food-population balance in the coming decades. Rice research must deal with a number of difficult problems to meet the challenge: raising the yield ceilings of the current available rice varieties, protecting the past yield gains in the irrigated ecosystem and using biotechnology tools to develop high yielding varieties for the rainfed systems that are tolerant to drought, submergence and problem soils. The speed and extent of meeting these challenges depends on the level of resources that can be mobilized to support crop improvement research in the public sector.

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Table 1a. Sources of growth in cereal production, World 1970-90 and 1990-2005

Cereals	1970-90			1990-2005		
	Yield	Area	Production	Yield	Area	Production
Rice	2.21	0.47	2.68	0.9	0.27	1.17
Wheat	2.54	0.28	2.82	1.11	-0.36	0.77
Maize	1.97	0.71	2.68	1.77	0.56	0.23
All cereals	2.29	0.44	2.73	1.34	0.08	1.42

Source: Analysis of trend with FAO time series

Table 1b. Sources of cereal production, Developing Countries: 1970-90 and 1990-2005

Cereals	1970-90			1990-2005		
	Yield	Area	Production	Yield	Area	Production
Rice	2.35	0.49	2.84	0.92	0.31	1.23
Wheat	3.75	0.88	4.62	1.27	-0.35	0.91
Maize	2.65	0.97	3.61	1.64	0.66	2.3
All cereals	2.68	0.73	3.41	1.2	0.21	1.41

Source: Analysis of trend with FAO time series data

Table 2. Estimates of the net gains from the adoption of modern rice varieties.

Country	Rice yield (kg ha-1)		Cost in rice equivalent (kg ha-1)		Net gain from the adoption of MV kg ha-1
	MV	**TV**	MV	TV	
Bangladesh	3980	1970	2614	1600	996
West Bengal, India	4174	1921	2631	1475	1097
Vietnam	4805	2297	4044	2419	883
Philippines	3780	2100	2363	1579	896
Indonesia	5176	3093	1759	521	845
Average	4383	2276	2683	1519	943

Note: For Indonesia, the figures for modern varieties (MV) are for Java, where adoption rate is almost complete, while the figures for traditional varieties (TV) are for Kalimantan, where most of the area is grown with traditional varieties. The traditional varieties fetch a higher price in the market because of better quality. The yields for traditional varieties are adjusted for the price premium over the modern varieties.

Source: Hossain M. et al (2003)

Table 3. Sources of growth in rice production in different regions: 1970-90 and 1990-2005

Regions	1970-90			1990-2005		
	Yield	Area	Production	Yield	Area	Production
Asia	2.32	0.37	2.69	0.89	0.19	1.07
East Asia	2.72	-0.37	2.35	0.58	-1.07	-0.49
Southeast Asia	2.51	0.91	3.42	1.46	1.18	2.64
South Asia	2.14	0.57	2.71	1.4	0.25	1.65
Sub-Saharan Africa	0.94	2.22	3.17	-0.73	2.62	1.89
Latin America	1.94	0.78	2.72	3.04	-0.56	2.48

Source: Analysis of trend with FAO time series data

Table 4. Trends in rice yield, by country, 1969-2005

Region	Yield (t/ha) 2003-05	Intercept	Dummy (1990-2004)		Time		Time*Dummy		R2	Growth rate 1970-90	Growth rate 1990-04
			Coef-ficient	t-value	Coef-ficient	t-value	Coef-ficient	t-value			
Bangladesh	3.62	0.4719	-0.1900	-2.28	0.0200	12.84	0.0087	2.75	0.97	2.00	2.87
Bolivia	2.44	0.3942	0.0851	0.33	0.0072	1.50	0.0001	0.01	0.43	0.72	0.73
Brazil	3.39	0.2849	-0.2748	-2.08	0.0163	6.62	0.0187	3.72	0.95	1.63	3.51
Cambodia	2.01	0.1883	-0.5532	-2.09	0.0015	0.31	0.0306	3.04	0.67	0.15	3.21
China	6.24	1.1175	0.5007	6.48	0.0312	21.64	-0.0246	-8.37	0.97	3.12	0.66
Colombia	5.23	1.2699	-0.3879	-2.75	0.0145	5.51	0.0076	1.42	0.67	1.45	2.22
Congo, DemRep	0.76	-0.2730	-0.0409	-0.77	0.0039	3.93	-0.0030	-1.46	0.58	0.39	0.09
Côte d'Ivoire	2.30	0.1664	-1.4080	-4.82	-0.0011	-0.19	0.0653	5.87	0.78	-0.11	6.43
Cuba	3.38	0.6618	-0.6106	-2.41	0.0320	6.76	0.0014	0.14	0.65	3.20	3.34
Dominican Rep	4.88	0.9494	0.6224	3.30	0.0310	8.82	-0.0312	-4.35	0.82	3.10	-0.02
Ecuador	3.99	1.0098	-0.2308	-1.38	0.0046	1.47	0.0121	1.90	0.62	0.46	1.67
Egypt	9.71	1.6154	-0.0521	-0.70	0.0105	7.58	0.0099	3.50	0.97	1.05	2.04
Ghana	2.03	-0.1420	0.4113	1.19	0.0124	1.91	0.0009	0.07	0.77	1.24	1.33
Guinea	1.71	-0.1257	0.0050	0.04	-0.0004	-0.16	0.0189	3.61	0.93	-0.04	1.85
Guyana	3.86	0.5954	0.4952	3.00	0.0337	10.92	-0.0253	-4.02	0.89	3.37	0.84
India	3.03	0.4299	0.3375	3.14	0.0229	11.43	-0.0130	-3.19	0.94	2.29	0.99
Indonesia	4.55	0.8073	0.5808	9.75	0.0334	30.05	-0.0302	-13.32	0.98	3.34	0.32
Iran	5.37	1.1004	-0.2086	-1.20	0.0085	2.61	0.0113	1.71	0.74	0.85	1.98
Italy	6.37	1.5556	0.0397	0.25	0.0111	3.77	-0.0042	-0.71	0.50	1.11	0.69
Japan	6.27	1.7241	-0.1192	-0.92	0.0047	1.94	0.0031	0.64	0.28	0.47	0.79
Korea,DPR	4.05	1.5856	1.0334	2.65	-0.0199	-2.73	-0.0208	-1.40	0.35	-1.99	-4.08
Korea,Rep	6.47	1.5722	0.1149	0.69	0.0162	5.20	-0.0102	-1.61	0.56	1.62	0.59
Laos	3.20	0.1075	0.1807	1.02	0.0322	9.70	-0.0068	-1.00	0.93	3.22	2.54
Liberia	0.89	0.2080	0.0616	0.32	-0.0003	-0.07	-0.0068	-0.92	0.33	-0.03	-0.71
Madagascar	2.42	0.5948	-0.1226	-1.25	0.0021	1.13	0.0083	2.24	0.72	0.21	1.04
Malaysia	3.30	0.9311	-0.0236	-0.25	0.0030	1.76	0.0047	1.33	0.76	0.30	0.77

(Cont.) Table 4. Trends in rice yield, by country, 1969-2005

Region	Yield (t/ha) 2003-05	Intercept	Dummy (1990-2004) Coef-ficient	t-value	Time Coef-ficient	t-value	Time*Dummy Coef-ficient	t-value	R2	Growth rate 1970-90	Growth rate 1990-04
Mali	1.81	-0.0983	0.4942	1.42	0.0160	2.46	-0.0083	-0.63	0.70	1.60	0.77
Mozambique	1.08	0.2206	-2.0944	-4.76	-0.0246	-3.00	0.0840	5.01	0.45	-2.46	5.94
Myanmar	3.80	0.4692	0.1320	0.84	0.0366	12.51	-0.0166	-2.78	0.90	3.66	2.00
Nepal	2.79	0.5959	-0.2488	-1.58	0.0067	2.29	0.0128	2.13	0.73	0.67	1.95
Nigeria	0.96	0.3441	1.6024	7.22	0.0232	5.61	-0.0783	-9.26	0.79	2.32	-5.51
Pakistan	2.96	0.8316	-0.2736	-2.97	0.0034	1.96	0.0127	3.62	0.78	0.34	1.61
Panama	2.36	0.2526	0.2983	1.98	0.0286	10.15	-0.0205	-3.56	0.84	2.86	0.81
Peru	6.54	1.3757	-0.1556	-1.90	0.0113	7.40	0.0084	2.69	0.94	1.13	1.97
Philippines	3.49	0.3955	0.2401	1.88	0.0329	13.79	-0.0164	-3.38	0.93	3.29	1.64
SierraLeone	1.26	0.3646	0.0085	0.06	-0.0050	-2.04	0.0000	0.00	0.34	-0.50	-0.50
Spain	7.31	1.7981	-0.2613	-3.16	0.0009	0.55	0.0127	4.04	0.73	0.09	1.36
SriLanka	3.50	0.6716	0.1441	0.96	0.0235	8.40	-0.0106	-1.85	0.84	2.35	1.30
Tanzania	1.90	0.0591	0.0547	0.13	0.0240	3.17	-0.0117	-0.75	0.32	2.40	1.23
Thailand	2.63	0.6000	-0.1211	-1.43	0.0055	3.49	0.0088	2.72	0.89	0.55	1.43
Uruguay	6.71	1.3336	-0.2900	-1.71	0.0133	4.21	0.0117	1.80	0.79	1.33	2.50
USA	7.55	1.5611	-0.0478	-0.53	0.0121	7.22	0.0019	0.57	0.89	1.21	1.41
VietNam	4.80	0.6283	-0.1397	-1.00	0.0219	8.45	0.0089	1.69	0.94	2.19	3.09

Table 5. Trends in rice area, by country, 1969-2005

Region	Area (000Ha) 2003-05	Inter-cept	Dummy (1990-2004) Coef-ficient	t-value	Time Coef-ficient	t-value	Time*Dummy Coef-ficient	t-value	R2	Growth rate 1970-90	Growth rate 1990-04
Bangladesh	10941	9.1898	-0.1550	-3.57	0.0032	4.00	0.0043	2.58	0.63	0.32	0.75
Bolivia	141	3.8674	0.6668	2.07	0.0352	5.84	-0.0217	-1.77	0.83	3.52	1.34
Brazil	3617	8.5383	0.2160	0.91	0.0037	0.84	-0.0223	-2.48	0.69	0.37	-1.86
Cambodia	2167	7.0557	-0.0474	-0.09	0.0113	1.16	0.0076	0.38	0.35	1.13	1.89
China	28232	10.4741	0.1471	2.04	-0.0031	-2.31	-0.0071	-2.59	0.75	-0.31	-1.02
Colombia	501	5.6272	-0.0361	-0.16	0.0257	5.97	-0.0085	-0.97	0.65	2.57	1.72
Congo,DemRep	417	5.3804	1.4347	11.68	0.0337	14.70	-0.0565	-12.09	0.95	3.37	-2.28
Côted'Ivoire	471	5.6347	1.2292	6.52	0.0313	8.88	-0.0521	-7.25	0.83	3.13	-2.08
Cuba	183	5.1493	-0.5290	-1.90	-0.0059	-1.13	0.0248	2.34	0.19	-0.59	1.89
DominicanRep	120	4.3734	-0.4315	-1.71	0.0176	3.73	0.0091	0.95	0.52	1.76	2.67
Ecuador	333	4.2331	1.5929	4.56	0.0606	9.30	-0.0603	-4.54	0.90	6.06	0.03
Egypt	643	6.1615	-0.3156	-2.75	-0.0091	-4.23	0.0275	6.29	0.89	-0.91	1.84
Ghana	119	4.3020	-0.5426	-1.17	-0.0028	-0.32	0.0341	1.94	0.43	-0.28	3.13
Guinea	525	6.1222	-0.7786	-3.30	-0.0023	-0.51	0.0297	3.31	0.29	-0.23	2.74
Guyana	130	4.7851	-0.8411	-2.91	-0.0252	-4.66	0.0536	4.86	0.61	-2.52	2.84
India	42570	10.5298	0.1299	2.63	0.0055	6.01	-0.0051	-2.73	0.78	0.55	0.04
Indonesia	11734	8.9683	0.1643	3.56	0.0134	15.54	-0.0062	-3.54	0.97	1.34	0.72
Iran	610	5.9128	0.3928	3.28	0.0155	6.95	-0.0134	-2.94	0.87	1.55	0.21
Italy	223	5.1546	0.2847	3.36	0.0060	3.78	-0.0068	-2.11	0.84	0.60	-0.08
Japan	1682	7.9972	0.1600	2.07	-0.0175	-12.12	-0.0038	-1.29	0.95	-1.75	-2.13
Korea,DPR	586	6.3329	0.0725	0.81	0.0085	5.07	-0.0098	-2.88	0.53	0.85	-0.13
Korea,Rep	999	7.0859	0.1947	5.28	0.0022	3.24	-0.0127	-9.06	0.93	0.22	-1.05
Laos	756	6.5043	-0.8674	-5.35	-0.0035	-1.16	0.0325	5.26	0.48	-0.35	2.90
Liberia	120	5.1097	-1.7384	-3.97	0.0181	2.21	0.0257	1.54	0.71	1.81	4.38
Madagascar	1222	6.9338	0.0168	0.25	0.0077	6.17	-0.0032	-1.26	0.68	0.77	0.45
Malaysia	675	6.6027	-0.0448	-0.54	-0.0058	-3.74	0.0047	1.48	0.32	-0.58	-0.11
Mali	436	5.0748	-0.5646	-1.89	0.0089	1.59	0.0361	3.17	0.83	0.89	4.49

(Cont.) Table 5. Trends in rice area, by country, 1969-2005

Region	Area (000Ha) 2003-05	Inter-cept	Dummy (1990-2004) Coef-ficient	t-value	Time Coef-ficient	t-value	Time*Dummy Coef-ficient	t-value	R2	Growth rate 1970-90	Growth rate 1990-04
Mozambique	179	4.2602	-0.4467	-3.36	0.0214	8.61	0.0195	3.85	0.95	2.14	4.09
Myanmar	6266	8.4822	-0.3339	-3.96	-0.0020	-1.28	0.0199	6.21	0.87	-0.20	1.79
Nepal	1537	7.0551	-0.0267	-0.47	0.0104	9.81	-0.0009	-0.42	0.90	1.04	0.95
Nigeria	3646	5.2485	0.5864	1.46	0.0838	11.17	-0.0193	-1.26	0.95	8.38	6.46
Pakistan	2494	7.3356	0.0226	0.21	0.0170	8.42	-0.0041	-1.01	0.86	1.70	1.28
Panama	136	4.7184	-0.9763	-4.27	-0.0120	-2.81	0.0422	4.84	0.42	-1.20	3.02
Peru	321	4.6919	-0.7424	-2.88	0.0316	6.56	0.0225	2.29	0.85	3.16	5.41
Philippines	4083	8.1384	-0.3674	-3.60	-0.0006	-0.29	0.0165	4.25	0.61	-0.06	1.60
SierraLeone	210	5.8748	1.1969	6.32	0.0040	1.12	-0.0562	-7.79	0.84	0.40	-5.22
Spain	119	4.0919	-0.8383	-2.55	0.0100	1.63	0.0352	2.82	0.63	1.00	4.52
SriLanka	840	6.4895	0.1084	0.55	0.0116	3.17	-0.0085	-1.14	0.31	1.16	0.31
Tanzania	353	4.9607	0.9953	3.12	0.0469	7.89	-0.0455	-3.75	0.82	4.69	0.14
Thailand	9864	8.8790	0.0068	0.07	0.0165	9.23	-0.0070	-1.92	0.80	1.65	0.95
Uruguay	188	3.4962	0.5544	2.78	0.0525	14.06	-0.0177	-2.33	0.97	5.25	3.47
USA	1304	6.7648	0.1423	0.56	0.0157	3.29	-0.0075	-0.77	0.49	1.57	0.82
VietNam	7412	8.4800	0.0133	0.24	0.0107	10.40	0.0022	1.04	0.96	1.07	1.29

Table 6. Trends in rice yield, Indian states 1970-2004

Region	Yield (t/ha)	Intercept	Dummy (1990-2004) Coef-ficient	Dummy (1990-2004) t-value	Time Coef-ficient	Time t-value	Time*Dummy Coef-ficient	Time*Dummy t-value	R2	Growth rate 1970-90	Growth rate 1990-04
AndhraPradesh	4.60	0.7489	0.1783	1.38	0.0279	11.28	-0.0112	-2.16	0.92	2.79	1.67
Assam	2.21	0.3705	0.0444	0.42	0.0091	4.54	0.0032	0.75	0.89	0.91	1.23
Bihar-O	2.08	0.1987	-0.2951	-1.07	0.0157	3.00	0.0119	1.08	0.64	1.57	2.76
Gujarat	2.84	0.2538	0.2721	0.47	0.0222	2.03	-0.0138	-0.60	0.27	2.22	0.84
Haryana	4.41	0.9817	0.3830	1.63	0.0236	5.26	-0.0230	-2.45	0.58	2.36	0.06
Jammu&Kashmir	3.31	0.9416	0.1142	0.52	0.0115	2.75	-0.0124	-1.42	0.21	1.15	-0.09
Karnataka	3.48	0.9760	0.3425	2.68	0.0067	2.75	-0.0088	-1.72	0.76	0.67	-0.21
Kerala	3.33	0.7867	0.0959	1.60	0.0110	9.68	-0.0021	-0.86	0.95	1.10	0.90
MadhyaPradesh-O	1.01	0.0037	0.6746	1.58	0.0165	2.03	-0.0262	-1.54	0.31	1.65	-0.97
Maharashtra	2.77	0.4733	0.3934	1.16	0.0189	2.92	-0.0196	-1.44	0.36	1.89	-0.06
Orissa	2.27	0.1783	0.6949	2.04	0.0188	2.90	-0.0274	-2.01	0.48	1.88	-0.85
Punjab	5.91	1.1359	0.2518	1.66	0.0269	9.32	-0.0177	-2.93	0.84	2.69	0.92
Rajashtan	2.23	0.3651	-0.4571	-0.85	0.0028	0.27	0.0194	0.90	0.09	0.28	2.22
TamilNadu	4.17	0.9435	0.8507	3.50	0.0242	5.24	-0.0349	-3.60	0.72	2.42	-1.07
UttarPradesh-O	3.26	0.0553	0.7448	2.61	0.0432	7.94	-0.0330	-2.90	0.86	4.32	1.02
WestBengal	3.76	0.4955	0.1925	1.03	0.0230	6.49	-0.0039	-0.52	0.89	2.30	1.91

Table 7. Trends in rice area, Indian states, 1970-2004

Region	Area (000Ha)	Inter-cept	Dummy (1990-2004) Coef-ficient	t-value	Time Coef-ficient	t-value	Time*Dummy Coef-ficient	t-value	R2	Growth rate 1970-90	Growth rate 1990-04
AndhraPradesh	3081	8.1126	0.4588	2.34	0.0079	2.12	-0.0215	-2.74	0.21	0.79	-1.35
Assam	2541	7.6180	0.2043	3.51	0.0095	8.55	-0.0092	-3.95	0.86	0.95	0.03
Bihar-O	4968	8.5586	-0.1105	-1.13	0.0004	0.20	0.0015	0.37	0.30	0.04	0.18
Gujarat	675	6.0770	0.2409	1.13	0.0090	2.22	-0.0054	-0.63	0.60	0.90	0.36
Haryana	1028	5.5989	0.2382	1.19	0.0472	12.39	-0.0123	-1.55	0.95	4.72	3.48
Jammu&Kashmir	271	5.4501	0.3564	4.26	0.0096	6.03	-0.0180	-5.38	0.61	0.96	-0.83
Karnataka	1279	7.0033	0.2630	2.00	0.0025	1.01	-0.0054	-1.02	0.60	0.25	-0.28
Kerala	311	6.8653	0.6069	6.41	-0.0236	-13.09	-0.0309	-8.17	0.98	-2.36	-5.45
Madhya Pradesh-O	5459	8.4059	0.0681	2.48	0.0069	13.11	-0.0027	-2.48	0.96	0.69	0.41
Maharashtra	1535	7.2094	0.1807	2.77	0.0075	6.00	-0.0099	-3.78	0.61	0.75	-0.24
Orissa	4501	8.4178	0.0265	0.45	-0.0037	-3.30	0.0023	1.00	0.36	-0.37	-0.13
Punjab	2647	6.0669	1.1364	5.82	0.0866	23.26	-0.0661	-8.48	0.97	8.66	2.05
Rajashtan	101	5.0280	0.6104	1.61	-0.0068	-0.94	-0.0187	-1.24	0.13	-0.68	-2.56
TamilNadu	1909	7.9486	0.2858	1.39	-0.0188	-4.80	-0.0038	-0.47	0.61	-1.88	-2.26
UttarPradesh-O	6245	8.4113	-0.0238	-0.28	0.0111	6.88	-0.0012	-0.36	0.82	1.11	0.99
WestBengal	5857	8.5185	0.1251	1.65	0.0045	3.11	-0.0035	-1.15	0.70	0.45	0.10