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CONFRONTING THE ENVIRONMENTAL CONSEQUENCES OF THE GREEN REVOLUTION IN ASIA

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ABSTRACT

Intensive double or triple monocropping of rice has caused degradation of the paddy micro environment and reductions in rice yield growth in many irrigated areas in Asia. Problems include increased pest infestation, mining of soil micronutrients, reductions in nutrient-carrying capacity of the soil, build-up of soil toxicity, and salinity and waterlogging. Emerging sustainability problems in intensive rice agriculture show the need for a greater understanding of the physical, biological and ecological consequences of agricultural intensification and greater research attention to long term management of the agricultural resource base.

CONTENTS

CONFRONTING THE ENVIRONMENTAL CONSEQUENCES OF THE GREEN REVOLUTION IN ASIA[*]

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1. INTRODUCTION

The Green Revolution Strategy for increasing food production in Asia was based on the intensification of the lowlands through massive investments in irrigation infrastructure and in crop research. It was presumed that lowland intensification would lead to sustainable output growth over the long term. This strategy was meant to relieve pressures on the fragile uplands by creating employment opportunities in the lowlands. The strategy worked exceptionally well, for rice, up to the mid 1980s (Dalrymple, 1986; Herdt and Capule, 1983). Since then rice productivity growth has slowed down in the intensively cultivated areas across Asia (Rosegrant and Pingali, 1994).

Aggregate rice output growth rate for Asia increased from 2.1% per annum during 1955-65 to 2.9% per annum during 1965-80. Rice output growth rate surpassed annual population growth rate of 3.3%. Area expansion contributed nearly one-third of Asian rice output growth in the 1960s and one-fifth in the 1970s, but virtually none in the

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1980s. Rapid yield growth from 1965 to 1980, due to the adoption of modern rice varieties, was the primary contributor to rice output growth. In the past decade, however, the growth in aggregate rice output has declined to 1.5% per annum. Rice yield growth in Asia also declined sharply in the 1980s, from an annual growth rate of 2.6% in the 1970s to 1.5% during the period beginning in 1981 (Table 1). Even accounting for the income induced slow down in demand growth (Bouis, 1989, 1990a), projected demand increases are higher than the growth in rice production in the 1980s (Agcaoli and Rosegrant, 1992; IRRI, 1989).

Virtually all future output growth must come from increased rice yield per unit of land since the opportunities for further area expansion are minimal. At the field level, there is increasing evidence that the growth in rice yields has levelled off and there is a danger of future declines in yield growth, especially in the irrigated lowlands of Asia (Pingali, et al., 1990).

Intensification of irrigated land use, that is the movement from one to two or three crops of rice per year, has had positive and negative consequences. The positive impacts (especially employment and income effects) of intensification and the adoption of modern seed-fertilizer technology have been examined in great detail by the `green revolution' literature (Otsuka, et al., 1990). The post-green revolution phase of declining productivity and stagnant incomes has been analyzed only recently (Herdt, 1988; Barker and Chapman, 1988; Pingali, et al., 1990). This paper describes the factors contributing to the decline in productivity growth and the technological and policy options for reversing these trends.

Table 1--Rice: annual growth rates of area, production, and yield, Asia, 1957/59-1988/90

Countries/ Regions	1957/59- 1981/83- 1988/90 1988/90	1957/59- 1965/67	1965/67- 1973/75	1973/75- 1981/83	
Total Asia					
Area	0.73	0.85	1.09	0.24	0.25
Production	3.08	2.60	3.37	3.09	2.16
Yield	2.36	1.74	2.27	2.86	1.91
Southeast Asia					
Area	0.93	1.73	0.35	1.51	0.72
Production	3.24	3.17	3.29	4.28	2.29
Yield	2.32	1.46	2.94	3.22	1.57
South Asia					
Area	0.89	1.26	0.61	0.88	0.25
Production	2.33	3.13	1.63	2.57	2.31
Yield	1.45	1.89	1.02	1.71	2.03
China					
Area	0.52	-0.58	2.25	-1.07	-0.38
Production	3.55	2.62	3.92	2.98	1.25
Yield	3.03	3.21	1.68	4.06	1.63
India					
Area	0.67	1.21	0.74	0.46	0.34
Production	2.49	1.95	2.90	2.22	3.62
Yield	1.81	0.74	2.15	1.57	3.23

South Asia includes Bangladesh, Nepal, Pakistan, and Sri Lanka, excluding India.
Southeast Asia includes Burma, Indonesia, Kampuchea, Laos, Malaysia, Philippines, Thailand, and Vietnam.
Source of data: World Rice Statistics, 1990, IRRI.

2. FACTORS CONTRIBUTING TO THE DECLINE IN IRRIGATED RICE PRODUCTIVITY GROWTH

The slowdown in rice productivity growth in Asia since the 1980s has been caused by: i) world rice price induced factors; and ii) intensification induced factors. The long term decline in the world rice price has resulted in reduced investments for irrigation infrastructure, rice research and extension. At the same time, increased intensity of irrigated land use has led to increasing input requirements for sustaining current yield gains. This section argues that the combination of these factors has resulted in the observed declines in rice output growth.

WORLD RICE PRICE INDUCED DECLINE IN PRODUCTIVITY GROWTH

Declining rice productivity growth can be partly attributed to the long term decline in the world rice price. The world rice price has been on a declining trend in real terms since 1900, a decline which has sharpened in the 1980s (Mitchell, 1987). The declining price of rice has caused a direct shift of land out of rice and into more profitable cropping alternatives, and has slowed the growth in use of inputs and yields. Probably more important in the long run, the declining world price has caused a slowdown in investment in rice research and irrigation infrastructure.

DECLINING RESEARCH EXPENDITURE AND OUTPUT

There was a considerable expansion of international and national support for agricultural research during the past three decades. However, annual growth in real total research expenditures in Asia declined from 7.4% in the 1961 to 1980 period, to about 4.6% during the 1980s (Rosegrant and Pingali, 1993). Expenditures per researcher have nearly remained constant over this period, and are very low in Asia compared to Sub-Saharan Africa and Latin America. Pardey and Roseboom (1990) argue that this is partly due to economies of scale because of the relatively large size of research systems in Asia. Nevertheless the relatively low spending per researcher is cause for additional concern.

Hayami and Mooroka (1987) show that there has been a corresponding decline in rice research output over this period, as measured by the number of rice research publications. The growth in number of rice research publications increased from 2.8% for 1963-70 to 4.8% for 1969-79, and then declined sharply to 1.6% for 1979-85. Moreover, Hayami and Mooroka show that the decline in rice research output over this last period was directly related to the decline in world rice prices.

The declining trend in research expenditures is particularly troublesome because a broad range of evidence shows that investment in research have been among the most socially profitable avenues for public investments. Moreover, the available evidence show that the rates of return to agricultural research have been maintained in the 1980s, despite the popular perception that returns may have declined due to the failure to introduce new varieties that increase potential rice yields. The effective use of maintenance and adaptive research has sustained the rate of return to research (Evenson and Rosegrant, 1993). Continued reductions in research expenditures will therefore increase the difficulty of sustaining rice productivity growth.

DECLINING IRRIGATION INVESTMENT AND DEGRADATION OF IRRIGATION INFRASTRUCTURE

Since the mid-1960s, the growth rate of irrigated area in the world has declined by about 60%; in Asia, it has declined by 72%. Recent sharp reduction in irrigation investment is likely to further slow the rate of growth in area irrigated. Lending and assistance for the Asia region as a whole reached its peak in real terms in 1977-79, and by 1986/87 it was only about 50% of the 1977-79 level. For South Asia, the peak lending period was 1980-82, followed by a 50% drop in annual lending by 1986/87. The decline was even more precipitous in Southeast Asia, from a peak in annual average lending of $630 million in 1977-79 to $202 million in 1986/87 (Rosegrant and Pingali, 1993).

Some countries, notably India, have insulated their irrigation investment programs from this cut-back in international lending by increasing the use of domestic funds. However, most countries in Asia, for example Indonesia, the Philippines, and Thailand, have sharply reduced total spending on irrigation as international lending has decreased.

Among the factors contributing to the reductions in investment are the large public and foreign debt loads carried by most of the countries in the region, the declining share of unexploited irrigation development, and concerns about the environmental implications of irrigation projects (Rosegrant and Svendsen, 1990). However, the most important causes of declining investment appear to be the decline in world rice prices and the increasing real costs per hectare of new irrigation development (Rosegrant and Pasandaran, 1990; Rosegrant and Mongkolsmai, 1990; Svendsen and Ramirez, 1990). The full effects of these declines in irrigation investment on rice production are just beginning to be felt due to the lags in irrigation construction.

The problem is exacerbated by the poor maintenance of much of the existing irrigation infrastructure. Despite a relative shift in overall irrigation investment in the 1980s from new construction to rehabilitation and operations and maintenance, there is evidence of continued decline in the quality of existing irrigation infrastructure.

An analysis of 92 irrigation systems in Luzon Island of the Philippines, shows that almost a third of them have declining trends in wet and dry season irrigated areas and in wet and dry season rice yields (Masicat, et. al., 1990). Between 1979 and 1989, the absolute wet and dry season irrigated area on Luzon declined by 20,466 hectares and 36,175 hectares, respectively.

The change in the relative price of rice versus non-rice crops has also increased intensification pressures on the upper watershed areas of the irrigation systems. The associated externalities on irrigation infrastructure, in terms of soil erosion leading to siltation of reservoirs and the consequent reduction in the service area of irrigation systems, are discussed in Pingali and De Vera (1993).

3. INTENSIFICATION INDUCED DECLINE IN PRODUCTIVITY GROWTH

Does intensification of irrigated land use, independent of rice price effects, lead to a long term decline in rice productivity? Intensification is defined here as the permanent movement from one rice crop per year followed by a dry season fallow, to two or three consecutive rice crops per year on the same land. The consequences of intensification on the paddy resource base can be observed only over the long term and vary by agro-climatic and management factors.

The best illustration of the consequences of intensification, independent of price effects, can be found in the examination of yield trends from long term trails conducted on experiment stations. The long term continuous cropping experiment conducted by IRRI in the Philippines is an excellent example of such trials. This experiment, set up in 1963, has been monitoring the impact of rice monoculture (with three crops per year) and as of 1993 had completed 89 consecutive crops on the same plot (Cassman, et al., 1994).

Table 2 presents yield trends from this as well as other long term trials in the Philippines, India, Thailand and Bangladesh. The trends indicate that, even with the best available cultivars and scientific management, yields holding input levels constant decline over the long term. The declining yield trends in long term experiments has been documented by Flinn and De Datta (1984), Pingali, (1992), Cassman and Pingali (1993) and Cassman, et. al (1994).

Table 2--Growth in rice yield potential for selected Asian countries.

Locations	Annual Growth in Yields	
	Wet season	Dry season
Philippines (1966-88)		
IRRI	-1.29	-1.28
Maligaya Rice Research and Training Center	-1.01	+0.15
Visayas Rice Experiment Station	+0.18	+0.18[a]
Bicol Rice and Corn Experiment Station	-0.62	-0.38
India (1969-89)		
Coimbatore	-0.27[a]	0.44[a]
Raipur	-1.41	-
Pantnagar	-0.89	-
Rajendranagar	0.12[a]	-
Mandya	-1.11	-
Bangladesh (1977-88)		
Comilla	-1.8	-
Joydebpur	-0.13[a]	-
Thailand (1977-90)		
Chiang Mai	2.3	-
Suphanburi	-2.5	-
Chiang Rai	-1.8[a]	-

[a] Not significantly different from 0.0%.

Source: Growth rates for the Philippines were estimated using data from the long-term fertility trials conducted at the above experiment stations. For India, Bangladesh and Thailand, data from INGER were used.

At the farm level, declining yield trends are usually not observed since input levels are not held constant over time. However, in areas where intensive rice monoculture has been practiced over the past two to three decades, one does observe stagnant yields and/or declining trends in partial factor productivities, especially for fertilizers, and declining trends in total factor productivities (Pingali, et. al., 1990; Pingali, 1992; and Cassman and Pingali, 1993).

Consider the following intensively cultivated rice bowls of Southeast Asia: Central Luzon, Philippines, Central Plains, Thailand and West Java, Indonesia, for the period 1980-1989. Farm panel data sets for each of these locations indicate that in the decade of the 1980s the rate of growth in yields was lower than the rate of growth in input use (Pingali, 1992). In Central Luzon, a 13% yield increase over a ten year period was achieved with a 21% increase in fertilizers, and a 34% increase in seeds. In the Central Plains, for the same period, yields increased by 6.5%, while fertilizer levels increased by 24% and pesticides by 53%. Similarly, for West Java, yields increased by 23%, while fertilizer use increased by 65% and pesticide use increased by 69% (Pingali, 1992).

Clearly, productivity cannot be sustained over the long term in intensive rice monoculture systems. Intensive rice monoculture on the lowlands results in the following changes in production systems: i) rice paddies flooded for most of the year without adequate drying period; ii) increased reliance on inorganic fertilizers; iii) asymmetry of planting schedules; and iv) greater uniformity in the varieties cultivated. Over the long term, these changes impose significant environmental costs due to negative bio-physical impacts (Table 3).

Environmental consequences of rice monoculture systems vary by agro-climatic conditions, soil types and the source and the quality of the irrigation water. The following, however, are the most common: 1) build up of salinity and waterlogging; 2) micro-nutrient deficiencies and increased incidence of soil toxicities; 3) formation of a hardpan (subsoil compaction); 4) decline in soil nitrogen supplying capacity; and 5) increased pest build up and pest related yield losses. A brief description of each of the problems and the possibilities for reversing them are discussed below. At the farm level, long term changes in the bio-physical environment are manifested in terms of declining total factor productivity, profitability and input efficiencies.

SALINITY AND WATERLOGGING

Intensive use of irrigation water in areas with poor drainage can lead to a rise in the water table due to the continually recharge of ground water. In the semi-arid and arid zones this leads to salinity buildup while in the humid zone to waterlogging. Salinity is induced by an excess of evapotranspiration over rainfall causing a net upward movement of water through capillary action and the concentration of salts on the soil surface. The ground water itself need not be saline for salinity to build up, it can occur due to the long term evaporation of continuously recharged water of low salt content (Moorman and Van Breemen, 1978). High water tables prevent the flushing of salts from the surface soil. Postel (1989) estimates that 24% of the irrigated land world wide suffer from salinity problems, with India, China, United States, Pakistan, and Soviet Union being the most effected.

Table 3--Intensification induced degradation of the irrigated lowlands

RESOURCE BASE DEGRADATION	POSSIBLE/ PROBABLE CAUSES	FARM LEVEL INDICATORS OF RESOURCE DEGRADATION	ECONOMIC IMPACT
1. Build up of salinity/waterlogging	• poor design of irrigation systems (poor drainage) • intensive use of irrigation water	• reduced yields and/or reduced factor productivities • reduced cropping intensities • abandoned paddy lands in the extreme	
2. Increased incidence of soil toxicities and micro-nutrient deficiencies	• long term flooding/ water saturation of paddy soils • increased reliance on low quality irrigation water • depletion due to continuous rice monoculture • long term flooding/ water saturation on paddy soils	• reduced yields and/or reduced factor productivities • reduced yields and/or reduced factor productivities	• Declining trends in TFP • Declining profitability of rice cultivation
3. Hardpan (sub-soil compaction	• increased frequency of puddling (wet tillage)	• reduced flexibility for non-rice crop production in the dry season	
4. Changes in soil nitrogen supplying capacity	• changes inorganic matter quantity and quality due to slower rate of decomposition in continuously flooded soil	• declining efficiency of nitrogen fertilizer use	• Increased social costs of negative externalities on the environment and human health
5. Increased pest build up and pest related yield losses	• continuous rice monoculture • increased asymmetry of planting schedules • greater uniformity in varieties cultivated	• increased pesticide use	

In the short term salinity build up leads to reduced yields while in the long term it can lead to abandoning of paddy lands (Samad, et. al., 1992; Postel, 1989 and Mustafa, 1991).

Induced salinity problems are caused by excessive irrigation and poor drainage, especially, seepage from unlined canals. Poor irrigation system design is a primary factor inducing salinity problems. For instance, in Pakistan's Sind Province, large areas became saline after the introduction of extensive irrigation, which led to a rise of the water table from a depth of 20 to 30 meters to 1 to 2 meters within 20 years (Moorman and Van Breeman, 1978, other examples from South Asia can be found in Chambers, 1988). "Many irrigation projects in the drier rice growing areas suffer from a lack of insight into the dynamics of salinity" (Moorman and Van Breeman, 1978). In the humid zone, induced salinity build up is not as much a problem because the higher rainfall levels help flush out the accumulated salts, however, excessive water use and poor drainage cause problems of waterlogging in this zone. Waterlogged fields have lower productivity levels because lower rates of decomposition of organic matter, lower nitrogen availability and due to the accumulation of soil toxins. These issues are discussed further along in this section.

MICRO-NUTRIENT DEFICIENCIES AND SOIL TOXICITIES

Perennial flooding of rice lands and continuous rice mono-culture leads to increased incidence of micro-nutrient deficiencies and soil toxicities. Zinc deficiency and iron toxicity are the ones most commonly observed in the tropics. Waterlogging and salinity buildup aggravate these problems. In Asia zinc deficiency is regarded as a major limiting factor for wetland rice on about 2 million hectares (Ponnamperuma, 1974). These are mainly soils of low zinc content. Soils that are not initially of low zinc content also show signs of induced zinc deficiency due to rice monoculture. Drainage, even if temporary, helps alleviate this deficiency by increasing zinc availability (Lopes, 1980; Moormann and Van Breemen, 1978).

Most rice lands do not start off with any soil toxicities, however, toxicities may build up in some soils due to continuous flooding, increased reliance on poor quality irrigation water and impeded drainage. Iron toxicity is the most commonly observed soil toxicity due to intensive rice cultivation. Other toxicities are related directly to chemical content and pollutants in the incoming irrigation water, for instance, boron toxicity has been observed on the IRRI farm due to high levels of boron in the irrigation water.

WATER QUALITY

Rice productivity can be negatively effected by waterborne pollutants, both physical pollutants (such as silt and mine tailings) or dissolved chemicals that cause soil toxicities. Pollutant concentrations in irrigation water have been increasing due to: the degradation of the watersheds that replenish the irrigation systems (Pingali and De Vera, 1993; Castańeda and Bhuiyan, 1988); industrial pollutants discharged into the river system; and due to increased pumping of brackish ground water.

LONG TERM CHANGES IN SOIL PHYSICAL CHARACTERISTICS

Seasonal cycles of puddling (wet tillage) and drying, over the long term, lead to the formation of hard pans in paddy soils. The hard pan refers to compacted sub soil that is 5-10cm thick at depths of 10-40 cm from the soil surface. Compared to the surface soil, a plow pan has higher bulk density and less medium to large sized pores. Their permeability is generally lower than that of the overlying and deeper horizons. The formation of hardpans makes it difficult to grow non-rice crops after rice in a cropping system, and for the rice crop contributes to impeded root growth and ability to extract nutrients from the subsoil and leads to the build up of soil toxicities due to the perennial waterlogged condition of the soil layer above it.

A striking example of the problem of hardpans is seen in the rice-wheat cropping system in South Asia. With the advent of short duration rice and wheat varieties, over twelve million hectares of paddy lands are grown to wet season rice followed by a dry season wheat crop. The productivity of the wheat crop is affected by the poor establishment of wheat after puddled rice. If the hardpan is broken through deep tillage and soil structures are improved through the incorporation of organic matter it affects the productivity of the subsequent rice crop by reducing water holding capacity of the soil. Intensification has reduced the flexibility of dry season crop choice by changing the soil physical structure.

CHANGES IN SOIL NUTRIENT STATUS

The most commonly observed effect of intensive rice monoculture systems is a decline in the partial factor productivity of fertilizer nitrogen. Recent work at IRRI (Cassman, et. al., 1994 and Cassman and Pingali, 1993) indicates that this is due to a decline in the nitrogen supplying capacity of intensively cultivated wetland soils. In addition to this, increased incidence of phosphorus and potassium deficiency is also observed due to a lack of nutrient balance in fertilizers applied (De Datta et al., 1988).

Fertilized rice obtains 50-80% of its nitrogen requirement from the soil, and unfertilized rice obtains an even larger portion, mainly through the mineralization of organic matter (De Datta, 1981). The nitrogen supplying capacity of the soil depends on the previous cropping history and residue management, the quantity and quality of soil organic matter, and the moisture regime which affects the composition and activity of the microflora and fauna that govern the decomposition of soil organic matter and crop residues. In continuous cropping of flooded soils with two and sometimes three crops each year, organic matter is conserved or increased even when all straw is removed at harvest. This happens because of the large inputs of carbon from the aquatic biomass, such as green and blue green algae, and a slower rate of organic matter decomposition than for dry soils. Despite this conservation, the soil nitrogen supplying capacity decreases due to chemical changes in the organic matter and effects of flooded soils on microbial activity (Cassman et al., 1994). Phosphorus and potassium deficiencies are becoming widespread across Asia in areas not previously considered to be deficient. These deficiencies are directly related to the increase in cropping intensity and the predominance of year round irrigated rice production systems. For example, in China it is estimated that about two-thirds of agricultural land is now deficient in phosphorus, while in India nearly one-half of the districts have been classified as low in available phosphorus (Stone, 1986; Tandon, 1987; Desai and Gandhi, 1989). Desai and Gandhi note that this is due to the emphasis on nitrogen rather than a balanced application of all macro nutrients required for sustaining soil fertility. The result of unbalanced application of fertilizers has been a decline in the efficiency of fertilizer use over time (Desai and Gandhi, 1989; Stone, 1986; Ahmed, 1985).

INCREASING LOSSES DUE TO PESTS

The use of purchased inputs for plant protection was unimportant for rice prior to the mass introduction of modern varieties. Farmers had traditionally relied on host plant resistance, natural enemies, cultural methods, and mechanical methods such as hand weeding. Relatively minor pests--leaffolder, caseworm, armyworm and cutworm--started to cause noticeable losses in farmers' fields as area planted to modern varieties increased. The green leafhopper and brown planthopper (BPH) became major problems, the former as a vector of RTV and the latter as a direct result of insecticides killing its natural enemies (Teng, 1990). Soil pests, especially root nematodes, have also increased with intensification(Prot, et al., 1992 and Prot, 1993). Root nematodes hamper root growth and thereby effect rice yields. Pest build up in irrigated rice systems is related to: continuous rice cultivation; increased asymmetry of planting; uniformity of varieties cultivated; and injudicious pesticide use. Heong (1992) argues that prophylactic pesticide application has led to the disruption of the pest-predator balance and a resurgence of pest populations later in the crop season.

4. POLICIES FOR SUSTAINABLE PRODUCTIVITY GROWTH

The evidence thus points to increasing difficulty and higher cost in maintaining yield growth in rice, and the need for innovative policies to maintain sustainable productivity growth. The following sections of the paper will discuss policy options for sustainable growth in rice productivity in the areas of input management and crop diversification.

FERTILIZER

Achievement of relatively high levels of fertilizer use on rice in Asia has shifted concern from simply increasing the levels of use to improving the efficiency of fertilizer use. The two main aspects of increased efficiency of fertilizer use are improvement of the balance of fertilizer applications to address soil fertility constraints, and improvement of the placement and timing of fertilizer. Further work is needed to generate and extend viable technologies through location-specific research on soil fertility constraints and agronomic practices, improvement in extension services, and development of improved fertilizer supply and distribution systems.

An important policy initiative to improve the efficiency of fertilizer use is the reduction and eventual removal of fertilizer price subsidies. Subsidized fertilizer prices have induced increased use of fertilizers without encouraging efficiency of use, and have tended to favor the use of nitrogen fertilizers over other nutrients. Removal of fertilizer subsidies would correct the existing distortions in the fertilizer-labor price ratio and would make technologies that reduce fertilizer use more viable. The immediate impact would be on better timing and placement of fertilizers and the longer term impact would be on the use of organic fertilizers and fertility enhancing crop rotations, such as rice-legume systems.

Green manure technologies, especially the use of Azolla, have proven to be technically feasible but often not economically viable. Azolla used to be grown extensively in China and Vietnam when agricultural production was collectivized. Once the responsibility of production was transferred to the households, azolla production dropped dramatically in both countries. The opportunity cost of land and labor increased substantially after de-collectivization and the time taken for azolla production could be more profitably used for high value cash crop production and chemical fertilizers could be purchased with the additional income.

Where markets for secondary crops exist, the economically feasible organic fertilizer technique is a crop rotation that involves, for each year, a rice crop followed by a legume crop or two rice crops followed by a legume crop. Mungbean and soyabean are the most popular legumes used in rotation with rice. Nitrogen replenishment to the soil comes from two sources when a rice-legume system is practiced, first through nitrogen fixation and the second through residue incorporation. The net savings in chemical fertilizer for the rice crop following the legume crop is around 30%. Green manures ought to be viewed as a complement to chemical fertilizers and not as a substitute. An integrated nutrient management system in which green manures are used in association with more efficiently used chemical fertilizers would be viable when fertilizer subsidies are eliminated. An added advantage of such a system is that the legume, by acting as a break crop in the rice monoculture cycle, could disrupt the build up of insect and disease populations and prevent their carry over to the next crop. It could also help improve soil health and therefore the long term sustainability of the soil.

CROP PROTECTION

Efficiency gains in the utilization of pesticides appear to be possible through the use of integrated pest management. Adoption of IPM can increase the efficiency of pesticide use in two ways, by lowering the amount of pesticides applied without a consequent yield decline and by promoting non-chemical methods of pest control. Improved extension and training is crucial to make this technology work, as with techniques for increased fertilizer efficiency.

IPM uses resistant varieties, predator management and cultural practices along with judicious pesticide use to provide long term control of pest losses. A major force that has shaped the evolution of IPM field implementation on rice is the FAO Inter-Country Program for Integrated Pest Management for South and Southeast Asia. The program has encouraged both technical accomplishments and significant policy changes in several governments in the form of official sanctions of IPM as the means of national plant protection. Official decrees supporting IPM implementation have been promulgated in the Philippines, Indonesia, India, Sri Lanka and Malaysia (Teng, 1990).

WATER MANAGEMENT

The traditional method of rice irrigation is to continuously flood the paddy so as to maintain a constant water level. This system is inefficient and causes long term sustainability problems. The emerging problems of waterlogging and salinity build up in the intensively cultivated irrigated lowlands, are related to this inefficient water management practice. Where water induced paddy land degradation sets in, it effects the efficiency of all other inputs used. In addition to paddy land degradation, this system of irrigation management: i) imposes uncertainty for the users at the lower end of the irrigation system, in terms of the timing and quantity of water received; and ii) it reduces the flexibility of crop choice for the farmer, especially in the dry season.

Recent research has shown that intermittent flooding in order to keep the soil continuously saturated (but with no standing water) provides water savings of 40% with no significant decline in yield (Tabbal, et. al., 1992). In the dry season, intermittent water supply to the paddies would also allow for non-rice crop with minimal drainage costs (IRRI, 1990). In general, water control and distribution facilities at the system level are flexible enough to accommodate such a change. There would have to be a change in system management, especially in terms of water allocation rules. Farmer incentives for adopting such a system would depend on a change in irrigation fee collection procedures. Irrigation fees are normally collected on a per hectare basis and not on the basis of the amount of water used by the farmer. Volumetric fees would improve farmer incentives for increasing water use efficiency. As the value of water increases with rapid economic growth leading to rapid growth in non-agricultural demand for water, establishment of markets in tradable property rights to water could provide more efficient incentives for conservation of water use in rice production, by inducing farmers to consider the full opportunity costs of water (Rosegrant and Binswanger, 1994).

CROP DIVERSIFICATION

With a stagnant technological yield frontier and limited current options for increasing input use efficiency, prospects are poor for sustaining incomes through intensive irrigated monoculture rice production. Rice farmer income would depend to a large extent on the opportunities for crop and income diversification. To an extent, crop diversification could also be viewed as a means of arresting (or reducing) the long term degradation of the paddy ecosystem. The progression to crop and income diversification has taken place smoothly in countries where product markets were allowed to operate relatively freely, such as Thailand. Successful transition from rice monoculture to a rice based farming system is induced by market forces and constrained by physical factors, and does not require direct government involvement or intervention. For a detailed discussion on the opportunities and constraints to diversification see Pingali (1990).

In the lowlands, diversification options are generally limited to the dry season, because the wet season crop often continues to be rice due to high drainage requirements. The uplands have historically been diversified, with crop choices responding to market conditions. The movement into or out of rice in the uplands is not a major issue for deliberation. In the lowlands, diversification in areas with good market access would be most profitable and feasible in the irrigated lowlands and for the dry season, because of greater reliability of water supply, and higher returns to diversification investments. This is especially true on well drained soils, while on poorly drained soils that are prone to waterlogging the profitability of diversification depends on the magnitude of the drainage investment requirements. For the rainfed lowlands, the opportunities for growing a post-rice, dry season, crop depend on the risk of water stress (which is related to rainfall distribution) and/or the availability of supplementary irrigation. The following generalization is possible, the irrigated lowlands, while having an absolute advantage in a rice-rice cropping pattern, may at the same time, have a comparative advantage in a rice-non-rice cropping pattern. The extent of the comparative advantage depends on physical constraints and market opportunities for non-rice crop production. On the other hand, during the wet season, the upland environments have both an absolute and a comparative advantage in non-rice crop production.

The switch from rice mono-culture to diversified farming requires substantial start up investments plus operating expenses. This switch is generally not possible without long term and seasonal credit arrangements. Where diversification has occurred successfully, farmers have managed to acquire credit through private or public sources. No special credit arrangements were necessary for promoting diversification. Diversified farmers have similarly managed, through private arrangements, to deal with the higher labor and power requirements, higher management and supervision requirements and the higher price and production risk requirements of non-rice crops relative to rice.

5. CONCLUSIONS

The current problems of sustaining productivity growth in the Asian lowlands indicate that these areas are as susceptible to environmental degradation as the more fragile uplands. Environmental impacts of intensification on the lowlands, although not easily observed, tend to have a significant long term impact food production and food supply. For instance, if current rice yields on the irrigated lowlands of Asia dropped by 5%, the impact on total rice production would be about 10 million mt per year, based on production figures for 1989-91, an amount nearly equal to the annual volume of rice traded in the world market.

The problem of sustainability of the lowlands does not emerge mainly because of the technology being used, but rather because of the intensity of land use itself and the choice of crops. Intensive rice monoculture systems over the long term are not sustainable without adequate changes in current technologies and management practices. The argument that rice has been sustainably cultivated in China, Japan, etc for centuries is not an argument against the current problems being faced in Asia. In these countries, until recently, one crop of rice was grown per year, and the fallow period during the dry season allowed the land to be rejuvenated.

The problem of sustaining productivity growth comes about because of inadequate attention to understanding and responding to the physical, biological and ecological consequences of agricultural intensification. The focus of research resources ought to shift from a fixation on yield improvements to a wholistic approach toward the long term management of the agricultural resource base. When yield per hectare is used as the only measure of productivity growth and the "true" costs of production are not considered then research resource allocation will be biased away from understanding the systemic problems causing productivity stagnation or decline. It is unlikely that there will be quick answers for reversing the current slowing trend in productivity growth, so sustained research investments are essential.

Sustaining productivity gains in the post-green revolution era will have to come from more efficient use of inputs, including land and labor. Technologies for enhancing input efficiencies (such as better fertilizer management, integrated pest management, etc) are more knowledge intensive and location specific than the modern seed-fertilizer technology that was characteristic of the green revolution. Productivity gains accrue to farmers who have the ability to learn about the new technologies; discriminate among technologies offered to them by the research system; adapt the technologies to their particular environmental conditions; and provide supervision input to ensure the appropriate application of the technology.

Finally, we ought to emphasize that the long term productivity of the lowlands, especially the state of irrigation infrastructure, is not independent of upper watershed degradation. Where this externality is not explicitly accounted for, there is an underinvestment of research resources for upland conservation. The Green Revolution strategy of increasing lowland productivity has to a large extent relieved the pressure on the uplands by providing employment opportunities for migrant labor. However, if the current trend towards stagnation/decline in lowland productivity persists, then one could expect a decline in employment opportunities in the lowlands and hence increased pressure on the uplands.

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