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Sustaining Rice-Wheat Production Systems: Socio-economic and Policy Issues

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Preface

The Rice-Wheat Consortium for the Indo-Gangetic Plains met on 1–3 July, 1998 in Kathmandu, Nepal for a conference on “Sustaining Rice-Wheat Production Systems: Socio-economic and Policy Issues”. Agricultural scientists and economists from India, Pakistan, Nepal, and Bangladesh as well as from international institutes (CIMMYT, IRRI, IIMI, ICRISAT, ICIMOD, and Cornell University) participated in the Conference. This group of scientists was brought together to discuss the modern intensive rice-wheat systems of the Indo-Gangetic plains which are currently the largest producers of food grain for South Asia. Recent signs indicate a slowdown in productivity growth of rice and wheat. Most of the initial gains in rice and wheat productivity in the early Green Revolution days came from the irrigated and high rainfall environments, the so-called favorable production environments. It is in these favorable environments that we note the largest slowdown in productivity growth. This is especially alarming since the South Asian population, in absolute terms, continues to increase dramatically and the demand for food grains increases steadily.

During the Conference, participants presented country-level and thematic papers on rice-wheat systems in South Asia. They also identified priority social science research areas for the Rice-Wheat Consortium. These research areas can be grouped into: (i) Policy issues; (ii) Farm–level constraints to sustaining productivity growth; and (iii) Systems approach: interdisciplinary research and long-term monitoring. Below is a summary of the recommendations from each of the working groups.

The key policy issues for further research agreed upon in the context of sustainability of rice-wheat systems were: (i) Globalization and liberalization policies and their impact on the sustainability of rice-wheat systems; (ii) Impact of input use policies on the sustainability of rice-wheat systems; (iii) Output marketing policies and sustainability of rice-wheat systems; and (iv) Technology policies to push the production frontier outward. A possible approach to the policy study would be to have concurrent parallel studies occurring in all four countries with a common methodology.

This group felt that their goals should be to better comprehend diverse regional economies, and to initiate better comparative and collaborative research at the farm level. In addition, another important goal, they agreed upon, was to enhance the understanding of comprehensive temporal patterns of productivity in terms of cropping-system scenarios, input use, and institutions and markets at the farm level.

The activities would include diagnostic and long-term surveys as well as collection of time series data regarding productivity and practices of rice-wheat systems vis-à-vis alternative systems. Some of the possible farm-level resource constraints that the group brainstormed were: (i) Land (size, fragmentation, and tenure, topography, soil fertility/health, salinity, organic matter, waterlogging and drainage, depletion of groundwater, land market); (ii) Labor (seasonality of labor use, skill, training, family vs. hired labor, labor control and wage rate, gender issues); (iii) Capital (availability and use of seed, fertilizer, pesticides, credit availability, quality and timeliness, and farm machinery); (iv) Management (skill, education, awareness, extension, and adoption and modification of practices); and (v) Marketing and infrastructure (location, transportation, storage, processing, and market information). All of these resource constraints could have an impact on productivity growth at the farm level, and the need for a better description of diverse regional economies and patterns of productivity is imperative.

The major future research issues that this group decided upon were the need to better measure sustainability (i.e. what is happening?), better diagnose causative factors behind the changes in sustainability (i.e. why is it happening?), understand the consequences of the changes in sustainability (i.e. what are they?), and analyze the role of technologies/policies/investments to address the changes (i.e. what can be done about it?). The following research activities were decided upon: (i) Review and evaluation of alternative sustainability indicators; (ii) Identification, assessment and compilation of existing data sources; (iii) Design and implementation of farm-level survey; (iv) Data analysis (TFP, production functions, variability indices, yield trends, sources of growth, financial and economic profitability, unit cost of production, output and input prices); and (v) Documentation and evaluation of policies/ technologies

The desired research outputs for future collaborative work are: (i) Identification and estimation of socio-economic and biophysical sustainability indicators; (ii) Identification of causal factors and assessment of their magnitude; (iii) Implications for food production and prices, food security, rural incomes and employment, health and the environment, social development (migration, gender, etc.), macro-economy (international trade); and (iv) Identification of policies and technologies for sustainability.

This meeting has established a network of social scientists interested in further collaborative work in the rice-wheat systems. There was definitely a recognition of the need to collaborate closely with the biological scientists working in the Rice-Wheat Consortium. Social scientists can help in the identification of policy options for sustaining rice-wheat productivity growth, and in communicating research results to policy makers. Selected papers from the Conference are presented in this volume.

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Rice-Wheat Cropping Systems in the Indo-Gangetic Plains: Policy Re-directions for Sustainable Resource Use

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Introduction

The last three decades or more have witnessed the phenomenal growth of cereal crop productivity in the developing world, particularly in rice and wheat in Asia. High levels of investments in research and infrastructure development, especially irrigation infrastructure, resulted in the rapid intensification of the lowlands. Consequently, the irrigated and the high rainfall lowland environments became the primary source of food supply for Asia's escalating population. The emergence of the rice-wheat system in South Asia as the most important source of food supply, is a testament to the success of the Green Revolution in wheat and rice.

Recent signs, however, indicate a slowdown in productivity growth of the primary cereals, rice and wheat, especially in the intensively-cultivated lowlands of Asia, and particularly in the intensively cultivated rice-wheat zones of South Asia. Slackening of infrastructure and research investments and reduced policy support partly explain the sluggish growth. This paper argues that in addition to the above factors, degradation of the lowland resource base due to intensive use, over the long term, also contributes to declining productivity growth rates. Intensification *per se* is not the root cause of lowland resource base degradation, but rather the policy environment that encouraged inappropriate land use and injudicious input use, especially water and chemical fertilizers.

Trade policies, output price policies as well as input subsidies have all contributed to the unsustainable use of the lowlands. The dual goals of food self-sufficiency and sustainable resource management are often mutually incompatible. Policies designed for achieving food self-sufficiency tend to undervalue goods not traded internationally, especially land and labor resources. As a result, food self-sufficiency in countries with an exhausted land resource, particularly the countries of South Asia, came at a high ecological and environmental cost. Appropriate policy reform, both at the macro as well as at the sector level will go a long way towards arresting and possibly reversing the current degradation trends.

This paper provides an extensive review of the existing evidence on intensification induced degradation in the rice-wheat systems of the Indo-Gangetic plains of South Asia. Policy re-directions and corrections that can contribute to arresting and/or reversing the current degradation trends are recommended.

Looking Back

In 1950–52 rice production for all of South Asia was only 47 million tonnes and by 1996–98 it was 161.5 million tonnes with India being the largest producer at 123 million tonnes. A similar story is noticeable in wheat production in South

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Table 1: Rice and wheat production (million tonnes) in South Asia, 1950-98.

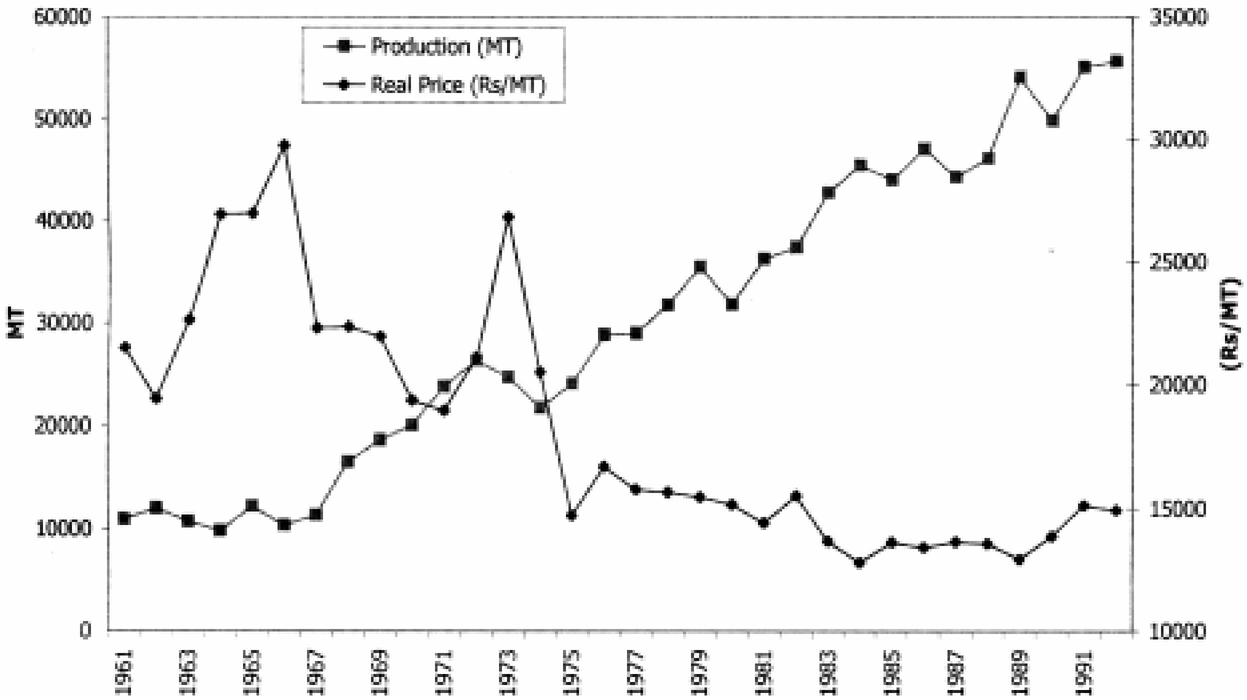
Country	1950–52	1960–62	1970–72	1980–82	1990–92	1993–95	1996–98
Rice production							
Bangladesh	10.9	14.1	15.6	20.9	27.1	26.3	28.2
India	32.4	49.2	62.3	77	109.4	120.5	123.1
Nepal	2.5	2.3	2.2	2.3	3.1	3.3	3.7
Pakistan	1.2	1.6	3.4	5	4.8	5.7	6.5
South Asia	**47.0**	**67.2**	**83.5**	**105.2**	**144.4**	**155.8**	**161.5**
Wheat production							
Bangladesh	<0.1	<0.1	0.1	1.1	1.1	1.2	1.5
India	6.7	11.3	25	38.9	55.7	61.6	65.8
Nepal	<0.1	0.1	0.2	0.4	0.8	1.0	1.0
Pakistan	3.1	4.0	6.9	11.7	15.8	16.3	17.4
South Asia	**9.8**	**15.4**	**32.2**	**52.1**	**73.4**	**80.1**	**85.8**

Asia. Production increased from 9.8 million tonnes in 1950–52 to 85.8 million tonnes in 1996–98, with India being the largest producer at around 66 million tonnes. Table 1 provides a disaggregated account of rice and wheat production from 1950–1998 for South Asia. It illustrates the quantum gains in production that have occurred in the region over time. Between 1966 and 1998 the growth rates of rice and wheat production in South Asia (2.75% and 4.9% per annum, respectively) exceeded the rate of growth in population (2.22% per annum), indicating an increase over time in the per capita availability of the two cereals.

The dramatic increase in production came from the intensification of land use, and to yield growth, the former attributable to investments in irrigation infrastructure and the latter to the adoption of modern seed-fertilizer technologies. For example, by 1979, almost 100% of the wheat planted in the Indian Punjab, the largest wheat producer in India, was to HYVs. The average wheat yield in the Indian Punjab doubled from 2 $t\ ha^{-1}$ in 1970–71 to over 4 $t\ ha^{-1}$ in 1993–94. The area under the rice-wheat cropping systems in India grew at 3.2% annually from 1959–62 to 1986–89.

While the production of wheat and rice has been increasing at such a rapid rate, real food prices have been declining steadily since the mid-1960s. Figure 1 provides an example for wheat in India. A similar decline in the real price of rice has been observed in India and across Asia (Pingali et al. 1997). The temporal decline in basic food prices has been especially beneficial to urban consumers, particularly the urban poor, as well as the rural poor who tend to be net purchasers of food.

The major factors that contributed to the initial success of the Green Revolution, and to the emergence of the rice-wheat system as an important source of food supply, were the following: introduction of the high-yielding, semi-dwarf varieties of rice and wheat (modern germplasm); infrastructure investments, especially irrigation systems; and political commitment and policy support. The latter two were as important as the first two in the rapid dissemination and



Source: FAOSTAT online database; IMF, International Financial Statistics, and Government of India

Figure 1. Wheat production and real price for India

adoption of modern technologies and the rapid growth in food production. The commitment to achieving food self-sufficiency was the driving political force that made the Green Revolution happen in South Asia. Micro- and macro-economic policies that promoted rapid productivity growth through the adoption of modern wheat and rice technologies were established in the mid-1960s.

In the early years, input price subsidies and output price supports were essential as they helped stimulate farmers to adopt new technologies. Unpriced irrigation water, cheap fertilizers, subsidized power supply and low-interest farm credit were some of the crucial supports provided by South Asian governments that made intensive rice-wheat production profitable. However prolonging the policies of input price subsidies into the post-Green Revolution period resulted in a distortion of farm-level incentives for efficient input use and lead to much of the degradation observed today.

While micro-policies have played an important role in leading South Asian farmers to unsustainable agricultural practices, macro-policy scenarios have been just as important. Since food self-sufficiency was the motivating factor for many of the policy measures during the 1970s and 1980s, macro-economic policies protected cereal prices through import restrictions and tariffs. Domestic prices were kept artificially high and excessive productive resources were devoted to the production of rice and wheat. These, were 'safe' crops which would get farmers assured prices at subsidized input prices. Thus, there was no real incentive for farmers to diversify from the rice-wheat rotation. The impact that past micro- and macro-economic policies have had on the rice-wheat resource base utilization and degradation are discussed below.

Ecological Consequences of Intensification

Intensive rice-wheat rotation on the lowlands results in the following changes in production systems: (i) seasonal wet and dry crop cycles over the long term; (ii) increased reliance on irrigation and 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 biophysical impacts.

The most common environmental consequences of lowland intensification are: (i) buildup of salinity and waterlogging; (ii) depletion/pollution of (ground)water resources; (iii) formation of a hardpan (subsoil compaction); (iv) changes in soil nutrient status, nutrient deficiencies and increased incidence of soil toxicities; and (v) increased pest buildup, pest-related yield losses and associated consequences of increased and injudicious pesticide use. A brief description of each of these problems and the possibilities for reversing them are discussed below. At the farm level, long-term changes in the biophysical environment are manifested in terms of declining total factor productivity, profitability, and input efficiencies. Many of the degradation problems, mentioned above, were policy-induced and the result of inappropriate and inefficient land, water and input use practices.

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 continual recharge of groundwater. 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 groundwater 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 Breeman 1978).

Induced salinity problems are caused by excessive irrigation and poor drainage (especially, seepage from unlined canals). Poor irrigation system design and management are primary factors leading to salinity problems. Irrigation water provided free or at a very low cost to the farmer tends to aggravate the problem. 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 20–30 m to 1–2 m within 20 years (Moorman and Van Breeman 1978); other examples from South Asia can be found in Chambers (1988), Abrol (1987), Dogra (1986) and Harrington, et al. (1992). Dogra (1986) estimates that in India, nearly 4.5 million hectares are affected by salinization and a further 6 million hectares by waterlogging. In the short term salinity buildup leads to reduced yields while in the long term it can lead to abandoning of crop lands (Samad et al. 1992; Postel 1989; Mustafa 1991).

In higher rainfall areas, such as in East India, induced salinity buildup is not as much a problem because the rain flushes 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 of lower decomposition rates of organic matter, lower nitrogen availability, and accumulation of soil toxins. In the case of wheat, low plant populations in some areas can be attributed to waterlogging, especially waterlogging occuring early in the growing season during germination and emergence stages of wheat. Hobbs et al. (1996) report for the Nepal Tarai that waterlogging reduced yields by half a tonne per hectare.

Groundwater depletion

Development of groundwater resources has been a significant driving force for agricultural intensification in many parts of Asia. The massive expansion of private sector tubewell irrigation in Bangladesh, India, and Pakistan is the most successful example of private sector irrigation development in Asia. A "groundwater revolution" in Bangladesh beginning in the 1980s was a key stimulant to rapid agricultural growth in the 1980s and early 1990s. Nearly 1.5 million hectares of land were newly irrigated after 1980, in significant part from installation of shallow tubewells spurred by deregulation of tubewell imports (Rogers et al. 1994).

However, just as excess use of un-priced irrigation water can lead to rising water tables and salinization, it can also lead to falling water tables, in tubewell irrigated areas, with negative environmental and productivity consequences. The problem of overdrafting of groundwater often occurs because individual pump irrigators have no incentive to optimize long-run extraction rates, since water left in the ground can be captured by other irrigators or potential future irrigators. Groundwater is depleted when pumping rates exceed the rate of natural recharge of the aquifer. While mining of both renewable and non-renewable water resources can be an optimal economic strategy, it is clear that groundwater overdrafting is excessive in many intensive agricultural areas in Asia. The problem of groundwater overdrafting is exacerbated when electricity for tubewell operations is subsidized.

Government intervention to prevent depletion of groundwater in the developing world has proven difficult to implement, subject to corruption, and in many cases very costly. The most successful tubewell development has been through small-scale private investment, which is widely dispersed and difficult to monitor. Only when private tubewell imports and markets were deregulated did the small-scale tubewell revolution take off in Bangladesh. An attempt at re-regulation through restrictions on well-siting slowed growth in tubewell adoption during 1985–1987 (Rogers et al. 1994). India has been ineffective at implementing licensing laws at the state level, where ownership of all water resources resides. Pakistan has no legal system for licensing groundwater withdrawals, and limited attempts to give ownership of underlying aquifers to municipalities have been challenged in the courts (Pingali and Rosegrant 1998).

Changes in soil nutrient status

The most commonly observed effect of intensive rice-wheat systems is a decline in the partial factor productivity of nitrogen fertilizer (Hobbs and Morris 1996). Recent work at IRRI (Cassman et al. 1994) indicates that the declining partial factor productivity of nitrogen in rice monoculture systems is due to a decline in the nitrogen supplying capacity of intensively cultivated wetland soils. Rice-wheat systems could be facing a similar phenomenon. Fertilized rice and wheat obtain 50–80% of their nitrogen requirement from the soil; unfertilized rice obtains an even larger portion, mainly through the mineralization of organic matter (De Datta 1981). The soil's capacity to provide nitrogen to the plant declines with continuous (two to three crops per year) flooded rice cultivation systems. Declining soil N supply results in declining factor productivity of chemical nitrogen, since soil N is a natural substitute for chemical nitrogen. The magnitude of yields foregone due to declining soil nitrogen supply are estimated by Cassman and Pingali (1993). Using long-term experiment data from the IRRI farm, Cassman and Pingali estimate the decline in yields to be around 30%, over a 20-year period, at all nitrogen levels.

In addition to nitrogen, phosphorus and potassium are the two other macro-nutrients demanded by the rice and wheat plants. 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 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).

Micronutrient deficiencies and soil toxicities: Perennial flooding of rice lands and continuous rice monoculture as well as the rice-rice-wheat rotation 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, often caused by poor water pricing and water management practices, aggravate these problems. In Asia, zinc deficiency is regarded as a major limiting factor for wetland rice on about 2 million hectares (Ponnamperuma 1974). In the rice-wheat zone also, zinc deficiency ranks number one in importance among the micro-nutrient deficiencies (Ivan Ortiz Monasterio, Personal Communication). 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 perennial water saturated conditions and continuous cropping. Drainage, even if temporary, helps alleviate this deficiency by increasing zinc availability (Lopes 1980; Moormann and van Breeman 1978).

Most irrigated lowlands 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, especially on soils where a hardpan is formed due to alternating wet and dry cycles. Iron toxicity is the most commonly observed soil toxicity due to intensive irrigated crop cultivation.

Once diagnosed at the farm level, micro-nutrient deficiencies are relatively straight forward to correct. Zinc deficiencies can be corrected by adding zinc, for instance. Diagnosis is itself not easy though; quite often micro-nutrient deficiencies are misdiagnosed as pest-related damage. In the case of soil toxicities, farm-level diagnosis is equally complicated and corrective actions are not as straight forward. In both cases however, the problem ought to be attacked at the cause rather than the cure stage. Periodic breaks in rice monoculture systems or rice-rice-wheat systems (two crops of rice followed by a crop of wheat) and improved water use efficiency go a long way towards reducing the incidence and magnitude of the above problems.

Long-term changes in soil physical characteristics: Seasonal cycles of puddling (wet tillage) and drying, over the long term, lead to the formation of hardpans in paddy soils. The hardpan refers to compacted subsoil that is 5–10 cm 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. A striking example of the problem of hardpans is seen in the rice-wheat cropping system in South Asia. The productivity of the wheat crop is affected by the poor establishment of wheat following 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 (Fujisaka, et al. 1994). Thus, intensification has reduced the flexibility of dry season crop choice by changing the soil physical structure.

Increasing losses due to pests

The use of purchased inputs for plant protection was unimportant for cereals 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. Agricultural intensification in general and continuous cropping of cereals in particular have increased the incidence of weed, insect and disease problems (Pingali and Gerpacio 1997; Hobbs and Morris 1996).

In the case of rice, relatively minor pests – leaffolder, caseworm, armyworm and cutworm – started to cause noticeable losses in farmers' fields as area planted to modern varieties increased. Hence the rapid increase in insecticide use in intensive rice monoculture systems (Rola and Pingali 1993). In the case of wheat, insecticide use is not very prevalent and fungicide use has been largely controlled by the development of varieties with resistance to major disease pressures. However, some diseases, such as *Helminthesporium sativum* (spot blotch) are on the rise in intensive wheat production zones, as well as the rice-wheat zone. Soil-borne diseases are also becoming an increasingly important factor in constraining yield growth in the rice-wheat areas of the Indo-Gangetic plains. On the other hand, the incidence of Karnal Bunt, a very important disease problem in wheat has been reduced with the advent of rice-wheat system, because the soil saturated conditions under rice are unfavorable to the disease build-up over crop cycles.

Insect and disease problems that have emerged have been exacerbated by crop management and pesticide use practices. Injudicious and indiscriminate pesticide application is related to policies that have made these chemicals easily and cheaply accessible. Heong et al. (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. Rola and Pingali (1993) have argued that pesticide use has been promoted by policy makers' misperceptions of pests and pest damage. Policy makers commonly perceive that modern variety use necessarily lead to increased pest-related crop losses and that modern cereal production is, therefore, not possible without high levels of chemical pest control.

Ecologically safe methods of weed management continue to be a major concern for the rice-wheat system. *Phalaris minor* became the major weed problem with the advent of the rice-wheat cropping system in South Asia (Hobbs and Morris 1996). Homogeneity of cropping patterns across large areas contributes to the rapid buildup and spread of *Phalaris*. Breaking up the cropping pattern reduces the weed buildup and herbicide resistance problems, however, cropping pattern choices are made on economic grounds rather than sustainability grounds.

The widespread availability of insect and disease resistant varieties for the major cereals has reduced the productivity benefits and the profitability of applying insecticides and fungicides. See Pingali and Gerpacio (1997) for a current review of the impact of host plant resistance for the major cereals, and Rola and Pingali (1993) for rice specific evidence. Even where resistant varieties are used one could anticipate pest problems due to a narrowing of genetic diversity on farmers' fields. When many farmers, in the same area, choose to grow the same high-yielding variety or ones with similar resistance genes, there is a lower level of genetic diversity than would most effectively protect against the emergence and spread of new disease strains (Heisey et al. 1997). However, increasing diversity on farmers' fields is not a simple proposition, the socially optimum level of diversity might differ quite substantially from the private optimum due to potential yield trade-offs and the cost of frequent varietal replacement. See Heisey et al. (1997) for an excellent case study of wheat rust management through enhanced genetic diversity in the Punjab of Pakistan.

Policies for Reversing the Current Degradation Trends

Meeting future food requirements in South Asia requires sustained productivity growth from the Indo-Gangetic plains. Continued high levels of investments in research and infrastructure improvement, as well as institutional and policy reforms are necessary to meet the above goal.

While resource base degradation is increasingly observed in the rice-wheat belt, intensification *per se* is not the root cause of environmental and ecological damage. Severe environmental degradation in intensified agriculture occurs mainly when incentives are incorrect due to bad policy or a lack of knowledge of the underlying processes of degradation.

Government intervention in the cereal market, especially through output price support and input subsidies, provided farmers incentives for increasing cereal productivity. In addition to highly subsidized irrigation water, South Asian farmers benefited from 'cheap' fertilizers, pesticides and credit. The net result was that rice monoculture systems as well as rice-wheat systems were extremely profitable through the decades of the 1970s and the 1980s, despite a long-term decline in the real world rice and wheat prices through this period.

Input subsidies that keep input prices low directly affect crop management practices at the farm level; they reduce farmer incentives for improving input use efficiency, that often requires farmer investment in learning about the technology and how best to use it. As Asian countries liberalize their agricultural sectors and move away from the single-minded pursuit of food self-sufficiency one can expect positive resource base and environmental benefits.

Many of the degradation problems observed in the intensively cultivated rice-wheat lands are not irreversible, appropriate policies will provide farmers the incentives to invest in more sustainable land and crop management practices. Techniques for improving fertilizer use efficiency, for example, are available but will only be viable at the farm level when fertilizer subsidies are removed. The same is the case with the adoption of zero-tillage, integrated pest management techniques, or more judicious water management. Table 2 provides details on policy interventions that contribute to resource base sustainability.

Table 2. Reversing the ecological/environmental degradation problems.

Resource base degradation problem	Possible/probable causes	Farm-level indicators of resource degradation	Economic impact	Possible technology intervention	Policy change
Buildup of salinity/ waterlogging	• Poor design of irrigation systems • Intensive use of irrigation water	• Reduced yields and/or reduced factor productivities • Reduced cropping intensities • Abandoned paddy lands in the extreme	Declining trends in TFP	• Improved irrigation system and design • Increased water use efficiency	Pricing irrigation water at its 'true' cost.
Hardpan (sub-soil compaction)	• Increased frequency of puddling (wet tillage)	• Reduced flexibility non-rice crop production in the dry season	Declining profitability of rice and wheat cultivation	• Improved farm-level drainage systems • Increased water use efficiency	• Pricing irrigation water at its 'true' cost
Changes in soil nitrogen supplying capacity	• Changes in organic matter quantity and quality • Long-term flooding/water saturation of paddy soils	• Declining efficiency of nitrogen fertilizer • Reduced yields and/or reduced factor productivities	Increased social costs of negative externalities on the enviornment and human health	• Crop diversification • Increased fertilizer use efficiency • Balance application of all nutrients	• Output price reform • Removal of fertilizer subsidies
Increased pest buildup and pest-related yield losses	• Continuous rice monoculture • Increased asymmetry of planting schedules • Greater uniformity in varieties cultivated	• Increased pesticide use		• Improved varieties with host plant resistance • Appropriate varietal turnover • Adoption and use	• Removal of pesticide subsidies • Investments in farmer education

In order to create incentives for efficient and more environmentally-friendly water allocation, water subsidies (and power subsidies for operation of tubewells) should be phased-out, with more realistic water charges in all sectors. In the longer term, markets in tradable water rights should be established where feasible. Establishment of secure water rights for water users is an important foundation for the establishment economic incentives for efficient water allocation. Moreover, responsibility for irrigation water management should be devolved where possible to autonomous local institutions with user representation and/or joint ownership. Full financial responsibility should be granted, including right to charge for water and services (Pingali and Rosegrant 1998).

To complement the approaches to crop management improvement in reducing fertilizer-related degradation problems, fertilizer subsidies ought to be removed to eliminate the incentive for unbalanced and excessive use. The financial costs of fertilizer subsidies to government treasuries are high. The true economic costs can be even greater, as subsidies soak up funds that could be used for alternative investments. The reduction and eventual removal of fertilizer price subsidies can substantially improve the efficiency of fertilizer use.

Non-price policies for fertility management are also important, including location-specific research on soil fertility constraints and agronomic practices, improvement in extension services, development of improved fertilizer supply and distribution systems, and development of physical and institutional infrastructure (Desai 1986; Desai 1988).

For various environmental and human health reasons (see Pingali and Roger, 1995, for detailed evidence in Philippine rice ecosystems), the integrated pest management (IPM) program has been vigorously pursued, particularly for rice. To make IPM more attractive, pesticides should never be subsidized since, as in the case of fertilizers, farmers would have no incentive to invest time in acquiring IPM skills. Removing all explicit and implicit subsidies on pesticides is essential to reduce pesticide use on farms.

With the progression toward global integration, the competitiveness of domestic cereal agriculture can only be maintained through dramatic reductions in the cost per unit of production. New technologies designed to significantly reduce the cost per unit of output produced, either through a shift in the yield frontier or through an increase in input use efficiencies, would substantially enhance farm level profitability of cereal crop production systems. Increasing input use efficiency would also contribute significantly to the long–term sustainability of intensive food crop production and help arrest many of the problems described above.

References

Abrol, I.P. 1987. Salinity and food production in the Indian sub-continent. Pages 109–113, *in* water and water policy in world food supplies. (Jordan, W.R., ed.). College Station, Texas A&M Univ. Press.

Ahmed, N. 1985. Fertilizer efficiency and crop yields in Pakistan. Phosphorus in Agriculture 89: 17–32.

Cassman, K.G. and **Pingali, P.L.** 1993. Extrapolating trends from long-term experiments to farmers fields: the case of irrigated rice systems in Asia, *in* proceedings of the Working Conference on Measuring Sustainability Using Long-Term Experiments. Rothamsted Experimental Station, 28–30 April 1993, funded by the Agricultural Science Division, The Rockefeller Foundation.

Cassman, K.G., De Datta, S.K., Olk, D.C., Alcantara, J., Samson, M., Descalsota, J., and **Dizon, M.** 1994. Yield decline and nitrogen balance in long-term experiments on continuous, irrigated rice systems in the tropics. Advances in Soil Science, Spl. issue.

Chambers, R. 1988. Managing canal irrigation: practical analysis from South Asia. Cambridge, UK, Press Syndicate of the University of Cambridge.

De Datta, S.K. 1981. Principles and practices of rice production. New York, USA, Wiley-Interscience Publication, John Wiley & Sons.

Desai, G.M. 1988. Development of fertilizer markets in South Asia: a comparative overview. Mimeo. Washington, DC., International Food Policy Research Institute.

Desai, G.M. 1986. Fertilizer use in India: the next stage in policy. Indian Journal of Agricultural Economics, Vol. 41:248–270.

Desai, G.M. and **Gandhi, V.** 1989. Phosphorus for sustainable agriculture growth in Asia – an assessment of alternative sources and management. *in*: proceedings of the Symposium on Phosphorus Requirements for Sustainable Agriculture in Asia and Pacific Region, March 6–10, Los Baños, Laguna, Philippines, International Rice Research Institute.

Dogra, B. 1986. The Indian experience with large dams. Pages 201-208, Vol. 2. *in* The social and environmental effects of large dams (Goldsmith, E. and Hildyard, N., eds.). London, UK, Wadebridge Ecological Center.

Fujisaka, J.S., Harrington, L. and **Hobbs, P.** 1994. Rice-wheat in South Asia: systems and long-term priorities established through diagnostic research. Agricultural Systems 46:169–187.

Harrington, L.W., Morris, M., Hobbs, P.R., Singh, V. Pal, Sharma, H.C., Singh, R.P., Chaudhary, M.K., and **Dhiman, S.D.** (eds.). 1992 Wheat and rice in Karnal and Kurukshetra Districts, Haryana, India - practices, problems and an agenda for action. Report from an exploratory survey, 22–29 March 1992. Haryana Agricultural University (HAU), Indian Council of Agricultural Research (ICAR), International Maize and Wheat Improvement Center (CIMMYT), International Rice Research Institute (IRRI).

Heisey, P.W., Smale, M., Byerlee, D., and **Sonza, E.** 1997. Wheat rusts and the costs of genetic diversity in the Punjab of Pakistan. American Journal of Agricultural Economics, 79 (August):726–737.

Heong, K.L., Aquino, G.B., and **Barrion, A.T.,** 1992. Population dynamics of plant and leafhoppers and their natural enemies in rice ecosystems in the Philippines. Crop Protection 11:371–379.

Hobbs, P. and **Morris, M.** 1996. Meeting South Asia's future food requirements from rice-wheat cropping systems: priority issues facing researchers in the post-green revolution era. Natural Resource Group Working Paper 96–01. CIMMYT, Mexico.

Hobbs, P.R., Harrington, L.W., Adhikary, C., Giri, G.S., Upadhyay, S.R., and **Adhikary, B.** 1996. Wheat and rice in the Nepal Tarai: farm resources and production practices in Rupandehi District. No. AECO95A Annual report R95A 53. Mexico, D.F., Mexico, Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT).

Lopes, A.S. 1980. Micronutrients in soils of the tropics as constraints to food production. *in*: Priorities for alleviating soil-related constraints to food production in the tropics. Jointly sponsored and published by the International Rice Research Institute, Los Baños, Laguna, Philippines and the New York State College of Agriculture and Life Sciences, Cornell University.

Moormann, F.R. and **van Breeman, N.** 1978. Rice: soil, water land. Los Baños, Laguna, Philippines, International Rice Research Institute (IRRI).

Mustafa, U. 1991. Economic impact of land degradation (salt affected and waterlogged soils) on rice production in Pakistan's Punjab. Ph.D. dissertation, College of Economics and Management. University of the Philippines at Los Baños (UPLB), College, Laguna, Philippines.

Pingali, P.L. and **Gerpacio, R.V.** 1997. Towards reduced pesticide use for cereal crops in Asia. Economics Working Paper No. 97–04. Mexico, D.F., Mexico, Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT).

Pingali, P.L., Hossain, M. and **Gerpacio, R.V.** 1997. Asian rice bowls: the returning crisis? IRRI/CAB International.

Pingali, P.L. and **Rosegrant, M.W.** 1998. Intensive food systems in Asia: can the degradation problems be reversed? Paper presented at the pre-conference workshop agricultural intensification, economic development and the environment of the Annual Meeting of the American Agricultural Economics Association, July 31–August 1, 1998, held in Salt Lake City, Utah.

Ponnamperuma, F. N. 1974. Micronutrient limitations in acid tropical rice soils. Pages 330–347 *in* Soil management in tropical America. (Bornemisza, E. and Alvarado, A., eds.). Raleigh, Soil Science Department, North Carolina State University.

Postel, S. 1989. Water for agriculture: facing the limits. Worldwatch Paper 93, December.

Rogers, P., Lydon, P., Seckler, D., and **Keith Pitman, G.T.** 1994. Water and development in Bangladesh: a retrospective on the flood action plan. Synthesis report prepared for the Bureau of Asia and the Near East of the U.S. Agency for International Development by the Irrigation Support Project for Asia and the Near East.

Rola, A.C. and **Pingali, P.L.** 1993. Pesticides, rice productivity, and farmers' health – an economic assessment. IRRI-World Resources Institute (WRI). Los Baños, Laguna, Philippines, International Rice Research Institute (IRRI).

Samad, M., Merrey, D., Vermillion, D., Fuchs-Casrsch, M., Mohtadullah, K. and **Lenton, R.** 1992. Irrigation management strategies for improving the performance of irrigated agriculture. Outlook on Agriculture. 21(4):279–286.

Stone, B. 1986. Chinese fertilizer application in the 1980s and 1990s: issues of growth, balances, allocation, efficiency and response. Pages 453–493 *in*: China's economy looks toward the year 2000. Volume 1. Washington, DC, Congress of the United States.

Tandon, H.L.S. 1987. Phosphorus research and agricultural production in India. New Delhi, India, Fertilizer Development and Consumption Organization.

Profitability of Wheat vs. Boro Rice in Bangladesh: Effects of Recent Commodity Price Changes

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Executive Summary

As Bangladesh nears self-sufficiency in cereals production, government policy makers have decided that the economic case for the future promotion of wheat warrants re-examination. This paper reviews the previously published findings of a joint IFPRI-CIMMYT study conducted in 1993–94 to assess the profitability of wheat production and presents updated results based on 1998 crop commodity prices. The IFPRI-CIMMYT study determined that wheat production is economically efficient in certain parts of the country and financially profitable. The updated results presented in this paper not only support the earlier findings, but they show that the financial profitability of wheat production relative to boro (winter) rice has increased during recent years as the result of commodity price changes.

As part of the original IFPRI-CIMMYT study, plot-level data were collected from 421 farms distributed throughout Bangladesh's wheat-growing areas in an effort to identify the factors which motivate farmers' planting decisions and influence the relative profitability of wheat vs. alternative crops. These data were used to develop enterprise budgets for two irrigated crops (wheat, boro rice) and three non-irrigated crops (wheat, oilseeds, pulses) grown during *rabi* season. Separate sets of crop budgets were developed for each of five wheat production zones, distinguished according to location, land elevation, soil texture, and other factors. For this study, the crop budgets were recalculated using 1998 commodity prices; input prices were left unchanged at 1993 levels.

The updated results generated using 1998 commodity prices support a key finding of IFPRI-CIMMYT study: boro rice frequently generates greater financial net returns to farmers' labor and management and to land than competing crops. What is striking about the updated profitability calculations, however, is the degree to which the financial profitability of wheat has increased relative to boro rice. Since 1993, the financial profitability of boro rice production has remained stagnant in most zones and even declined in some areas.

Introduction

Trends in Bangladesh's agricultural sector

With nearly 129 million people concentrated on 1,44,000 km^2, Bangladesh has a population density approaching 900 inhabitants/km^2 – one of the highest in the world. Despite efforts by the government to promote industrial development in order to diversify the economy and relieve pressure on the land, industrial growth has remained sluggish, and agriculture continues to be the mainstay of the economy. Agricultural activities today account for over one third of the GDP and employ nearly three quarters of the labor force.

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During the past 25 years, the agricultural sector has experienced a great deal of turbulence. Immediately after the achievement of independence in 1971, a series of disastrous harvests (attributable in large part to unfavorable weather) led to widespread food shortages, forcing the government to issue an urgent appeal to the international community for emergency relief. Massive imports of cereals, edible oils, and dairy products became a regular feature of the economy, and Bangladesh developed a reputation as one of the world's most impoverished nations. Following the return of more normal weather in the late 1970s, the agricultural sector recovered, and a succession of satisfactory harvests helped to replenish the nation's grain stocks. However, the recovery turned out to be temporary. With population growth outpacing growth in food production, regular imports of cereals became necessary to meet chronic production shortfalls.

Concerned about the widening structural gap between food supply and demand, in 1980 the government launched an ambitious plan to increase production of cereals with particular emphasis on the two primary staples, rice and wheat. Key components of this plan (as spelled out in the Second Five-Year Plan) included heavy investment in infrastructure for flood control, drainage, and irrigation; expansion of targeted crop production credit; subsidized distribution of seed of high-yielding modern varieties (MVs); and increased funding of agricultural research. In addition to these actions taken to increase the direct role of government in promoting food production, policy reforms were implemented to improve the efficiency of private markets for inputs. After a series of false starts, irrigation policy was liberalized, and responsibility for procurement and distribution of fertilizer was gradually ceded to the private sector. In time, these actions had a noticeable impact. Confounding the predictions of many skeptics, rice production increased rapidly, rising at an annual rate of 3.5% during the period 1987–93 and substantially reducing the need for food imports. While the national policy goal of self-sufficiency in cereals remains unrealised, clearly there are grounds for optimism.

Policy issues facing the government

Today, Bangladesh stands at the threshold of self-sufficiency in rice production, the most important food staple. Following a series of favorable harvests, domestically produced rice is abundantly available throughout the country in most years, and imports have practically disappeared. Private rice stocks are large relative to consumption need, and rice prices have eased significantly. If the most recent government statistics are to be believed, domestic supply already may have overtaken demand. Recent sharp declines in domestic rice prices at a time when the international price of rice has risen provide evidence to support this view.

Although the impressive gains in rice production constitute welcome news, achievement of national self-sufficiency in rice threatens to raise new and unfamiliar challenges for policy makers. Should current trends continue, the government soon may have to confront the problem of how to dispose of production surpluses. The problem is considerably complicated by the fact that policies for rice cannot be formulated independently of policies for other cereals which can substitute for rice in production and/or consumption. Nowhere are these linkages more evident than in the case of wheat. Because wheat competes with rice both in farmers' fields and on consumers' tables, policies affecting rice are inextricably linked to policies affecting wheat. Some analysts, noting the high yields of the boro rice (which is grown during the cool, dry *rabi* season when wheat is also grown), have concluded that wheat production represents a relatively inefficient use of resources and have argued that efforts to promote wheat production should be scaled back to allow greater emphasis to be placed on boro rice. This argument is reinforced by the perception that wheat is a relatively new crop in Bangladesh and is not well adapted to local agro-climatic conditions. Although not always backed up by rigorous scientific or economic analysis, such arguments have proved persuasive in the national policy debate.

Objectives of the Study

This report reviews the findings of a joint IFPRI-CIMMYT study carried out in 1993–94 to assess the returns to wheat production in different regions of Bangladesh (Morris et al. 1997). In addition, it presents updated results of the financial profitability analysis based on 1998 crop commodity prices. Faced with the prospect of achieving national self-sufficiency in rice, government policy makers (as well as the international donors who provide support to Bangladesh) have justifiably questioned whether or not wheat production should be aggressively promoted in the future, especially if continued support to wheat would have to come at the expense of support to rice and/or other more efficient crops. The question is certainly valid; given the scarcity of resources available for agricultural research and development, it would be difficult to justify continued investment in a crop whose production represents a wasteful use of resources.

Specific objectives of the original IFPRI-CIMMYT study included:

- To conduct a national survey of wheat producers in order to generate reliable farm-level data on farmers' practices for use in identifying major wheat-based cropping systems;
- To develop financial and economic budgets for wheat and major competing crops in order to establish the profitability of growing wheat from the point of view of farmers and from the point of view of the nation;
- To analyse the source of differences between financial and economic profitability in order to determine the effect on production incentives of policy-induced distortions;
- To explore how changes in key parameters such as production technologies, government policies, and international prices of key inputs and outputs are likely to affect the prevailing pattern of comparative advantage over the longer term; and
- To spell out implications of these results for policy makers and research administrators.

The objectives of the recalculations based on 1998 crop prices were to investigate how recent changes in crop prices may have affected prevailing patterns of financial profitability and to determine whether the conclusions of the original study remain valid.

Methodology

In the IFPRI-CIMMYT study, the comparative advantage of wheat in Bangladesh was estimated using a domestic resource cost (DRC) framework of analysis. The DRC framework uses standard methods of project appraisal to compare financial vs. economic profitability of competing production activities and to calculate rankings of their relative efficiency. These efficiency rankings provide an empirical measure of the prevailing pattern of comparative advantage. The methodology is described in detail by Morris et al. (1996 and 1997).

First, five major wheat production zones were identified. These five zones, which differed in their suitability for wheat production, were defined in terms of their geographical location (which has implications for climatic factors such as rainfall and temperature), land elevation, and soil type.

Second, for each of the five zones, crop budgets were developed for wheat and alternative crops. Input-output parameters for the crop budgets were estimated from detailed plot-level data collected by means of a national survey of wheat producers.

Third, production inputs and outputs were assigned two sets of prices: *financial prices and economic price.* Financial prices are the actual market prices paid or received by farmers inclusive of taxes, subsidies, and other transfers. Economic prices are shadow prices which have been adjusted to account for the effects of government policies, market failures, and other distortions.

Fourth, the crop budgets and the two price vectors were used to calculate the financial and economic profitability of wheat vs. alternative crops. Differences between financial and social profitability were then disaggregated to determine the direction and size of the distortions attributable to different government policies.

Fifth, information used in constructing the crop budgets was combined with information on financial and economic prices of production inputs and outputs to estimate distortions in the Bangladesh economy and to generate measures of production efficiency. The former revealed the effects of government policies on production incentives, while the latter enabled the most efficient crops to be identified in each zone. In the context of DRC analysis, production efficiency serves as an indicator of comparative advantage.

Sixth, sensitivity analysis was carried out to test the sensitivity of the comparative advantage indicators to changes in the values of key parameters whose future behaviour is difficult to predict with certainty. Sensitivity analysis was considered an essential part of the study, since any policy decisions made on the basis of comparative advantage considerations generally have long term implications. Thus, it is important to distinguish between dimensions of the current pattern of comparative advantage which can be expected to prevail over the longer run, and dimensions of the current pattern of comparative advantage which could change dramatically as the result of changes in production technology, changes in the national economy, and/or changes in the world economy.

For this paper, the financial profitability of wheat and competing crops was recalculated using 1998 commodity prices. Input use levels and input prices were left unchanged, an omission which should not greatly affect the *relative* profitability of the five crops included in the analysis, because inputs use levels are similar among the five crops. Yields also were left unchanged, which if anything penalizes wheat, because wheat yields have increased dramatically during the past few years while those of the other crops have remained essentially the same. To test these assumptions, input prices for urea, TSP, MP and seeds were changed to 1998 prices and only small relative changes occurred over all the crops. Crop price changed the financial profitability the greatest.

Principal Crops and Cropping Patterns

Rapid population growth in rural areas, coupled with a strong tradition of bequeathing land in equal proportions to all heirs (male and female), has led to increasing landlessness and extreme fragmentations of agricultural land holdings in Bangladesh. Farm size now averages less than one hectare. Under these circumstances, it is not surprising that agricultural production has become increasingly intensified. Double cropping is the norm in most areas, and triple cropping is becoming common.

Intensification has been made possible in large part by the introduction of irrigation technology. Cropping intensity increased from 1.33 in 1960–61 to 1.72 in 1990–91, mostly as a result of sharp increase in the cultivation of irrigated land during the *rabi* season. Currently in 1998, the cropping intensity is over 1.85. The increase in irrigated production was made possible by expansion in irrigation facilities, particularly systems served by deep tubewells (DTW) and shallow tubewells (STW). Government subsidies played an instrumental role in promoting the initial expansion of irrigation, although irrigation subsidies were reduced during the early 1990s.

It is difficult to generalize about cropping patterns in Bangladesh. Micro-level variability in agro-climatic conditions has fostered the emergence of a large number of localized cropping patterns. In most areas of the country, the cropping pattern revolves around one, two, and sometimes even three rice crops, reflecting the paramount importance of rice in the rural economy. The rice cropping calendar varies depending on variety (TV vs. MV), planting method (broadcast sowing vs. transplanting), water regime (rainfed vs. irrigated), and other factors. The first (spring) rice crop is the aus crop, which is planted during March and April during the early part of *kharif* season so as to benefit from the onset of the annual monsoon rains and harvested in July and August. The second and most important (summer) rice crop is the aman crop, which is grown in the middle of *kharif* season during the period of heaviest rainfall when water supplies are most reliable. An early aman crop may be broadcast sown as early as April, while a late aman crop (usually following an aus crop) may be transplanted as late July. The third (winter) rice crop is the boro crop, which is grown with irrigation during *rabi* season. Boro rice may be planted from late December all the way into early February, while the harvest ranges from April through June.

Turning from rice to other crops, the cropping calendar is equally complex. Sugarcane (which is grown year round) competes with aus and aman rice during *kharif* season. Jute (which is planted from April to May and harvested in August and September) can also compete with aus rice, while cotton (which is planted in July and August and harvested in February and March) may compete with late-planted aman rice. Wheat, pulses, oilseeds, roots and tubers, vegetables and spices are all grown during the period November-March (*rabi* season) and thus represent potential competitors for boro rice.

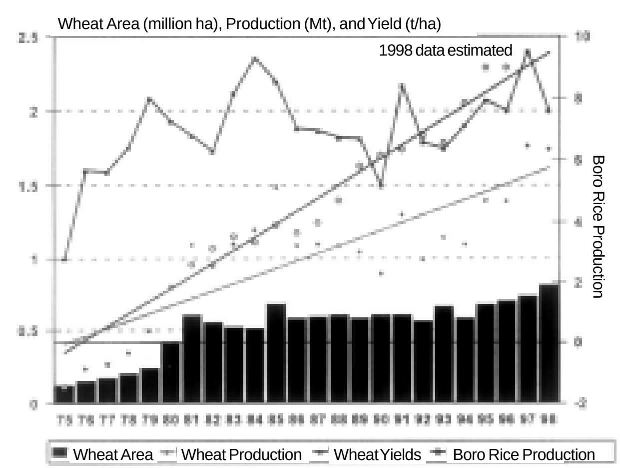
Trends in Cereal Productions

Rice is by far the most important cereal grown in Bangladesh. Approximately 75 % of the total cultivated area is planted to rice. Wheat ranks second in importance among cereals, followed at a considerable distance by millet, sorghum, and maize. Other important food crops include oilseeds (e.g. mustard, safflower, and sunflower), pulses (e.g. gram, mash, kheshari, masur, and mung), and potatoes; these are grown partly for home consumption and partly for sale.

Sugarcane and jute are major commercial crops grown throughout the country, while cotton, tobacco, and tea are important in localized areas.

In a country where rice is by far the most important food staple, any discussion of trends in cereal production must begin and end with rice. Three points are noteworthy about the rice economy. First, the aman crop is easily the most important rice crop, currently accounting for approximately 52% of total rice production, compared to 13% for the *aus* crop and 35% for the boro crop. Second, during the past two decades, the boro crop has increased dramatically in importance. The area planted to boro rice has grown rapidly with the expansion in irrigation. Because yields of boro rice are higher than those of the other two rice crops, the boro crop accounts for a disproportionately large share of total production. Twenty years ago, the boro crop accounted for only 10% of total rice production; today, it accounts for over one third of total rice production. Third, semidwarf MVs have steadily replaced tall TVs. Between 1972–73 and 1997–98, the proportion of total rice area planted to MVs rose from 11 to 50%, while the proportion of MV paddy in total production rose from 25 to 66%.

After rice, wheat ranks second in importance among cereals. Originally a minor crop, wheat has increased in importance during the past three decades as rising levels of imports (including large quantities of food aid) have led to rapid increases in consumption. In the wake of the 1974 famine, which occasioned extremely high wheat prices, farmers responded by sharply increasing the area planted to wheat (Choudhary 1993). Taking a cue from the farmers, government policy makers decided to encourage domestic production in order to reduce reliance on imports. Wheat promotion efforts initiated



Source: BBS FAO statistics

Figure 1. Wheat area, production, yields compared to boro (winter) rice production over the years

during the mid-1970s led to further rapid expansion in the area planted to wheat (Fig. 1), much of it concentrated in the northern and central parts of the country. It is instructive to examine the growth rates underlying these figures. The surge in wheat production was concentrated during the late 1970s and early 1980s, coinciding with government's campaign to promote the crop (Fig. 1). Over a ten-year period, area planted to wheat increased at a rate of 15% per year (starting from a very low base), while yields rose by more than 3% per year. These impressive rates of growth slowed dramatically during the late 1980s. Although the reasons for the slowdown remain subject to debate, two factors are frequently cited as having contributed to the deceleration in the expansion of wheat area and the stagnation of wheat yields. First, increased access to irrigation (resulting from government programs to develop irrigation infrastructure) encouraged many wheat growers to divert resources to irrigated boro rice (Fig. 1). Second, the late 1980s corresponded to the period when subsidies were removed from fertilizers and other inputs; sudden sharp increases in the prices of major inputs may have led wheat growers to cut back on use of purchased inputs, especially fertilizers. After peaking in 1984–85, wheat area and yields remained flat for the remainder of the decade. Only in the 1990s did wheat area and yields once again turn upwards.

The expansion in wheat area and growth in wheat yields realized during the late 1970s and early 1980s fuelled a tenfold increase in wheat production and led to a sharp reduction in the level of dependence on imports. Whereas Bangladesh was producing only around 15% of its wheat requirements in the mid-1970s, by the early 1990s about 45% of domestic consumption requirements were being met from local production. Nonetheless, despite these gains, annual wheat imports remain large in absolute terms.

Projecting future levels of wheat imports is complicated by the difficulty of predicting future wheat consumption levels. Although Bangladesh is generally thought of as a "rice-consuming" nation, consumption of wheat has been growing steadily. From 1968 to 1988, per capita wheat consumption rose at an average annual rate of 3.6%. This consumption growth, which began following the introduction of wheat into former East Pakistan, has apparently been driven by the influx of wheat food aid since independence. Currently, the per capita wheat consumption in Bangladesh is over 28 kg per year.

Wheat Production Zones

Five wheat production zones were identified for purposes of the IFPRI-CIMMYT study (Fig. 2). The five zones were elaborated using the results of the producer survey as well as information contained in the agro-ecological zones database published by the Food and Agriculture Organization (FAO) of the United Nations. We believe that the pattern of comparative advantage of wheat production in Bangladesh can be better understood if these five zones are distinguished, even though the zones do not comprise five contiguous areas which can be delineated clearly on a map. Wheat growers surveyed consistently placed wheat on their plots situated on the higher elevations with the lightest soil texture. Both factors are indicative of a greater difficulty to irrigate compared to boro rice. Because of this extensive micro-level variability in land elevation, soil texture, irrigation status, and other factors which influence farmers' planting decisions, the situation is confused, and pockets conforming to one set of zonal characteristics can sometimes be found surrounded by larger areas falling within another zone. Nevertheless, despite a certain amount of ambiguity associated with these zonal

Table 1. Relative importance of the five wheat production zones.

Zone	Location	Percent of national wheat area	Percent of national wheat production	Percent of national wheat marketing
1	Northwest	27	28	27
2	North central	22	22	16
3	South central	22	23	39
4	Southwest	27	25	16
5	Northeast	2	1	2
	Total	100	100	100

Source: Complied from BBS sources.

definitions, we are convinced that they remain useful as a tool for disaggregating the data collected during the producer survey and can help lead to a better understanding of the factors which influence the economics of wheat production.

Figure 2 shows the location of the survey districts. When districts, which were not surveyed, are subjectively classified into one of the five zones, the importance of each of the five zones in the national wheat economy can be estimated (Table 1). It is important to note that Zones 1–4 include most of the nation's major wheat-growing areas. Zone 5 represents a zone of relatively low wheat production potential which accounts for an insignificant portion of national wheat production.

In contrast to the wheat plots, which showed considerable variability, the plots being used to grow boro rice at the time the survey was conducted tended to be involved in one or two main cropping patterns. 67% of the boro rice plots were fully involved in an aman-boro rotation, while an additional 12% were involved in a boro rice-fallow rotation. Oilseeds-boro rice-aman rice and fallow-oilseeds-boro rice rotations were reported by 7 and 6% of farmers, respectively. Once again, the overlap between wheat and boro rice was minimal; virtually none of the plots used for growing boro rice had been used to grow wheat during the preceding *rabi* season. These results run counter to the conventional wisdom that boro rice has displaced wheat as the evidence suggests that wheat and boro rice are grown in different plots.

Figure 3 show the areas of Bangladesh delineated as to the suitability for wheat production. Clearly, there is a tremendous scope for increases in wheat area and production as its profitability rises.

Market Prices and Economic Prices

The enterprise budgets developed to determine the profitability of wheat vs. alternative crops were estimated using two sets of prices. *Financial prices* (i.e., the actual market prices paid by farmers for inputs and received for outputs) were used to determine financial profitability. *Economic prices* (i.e. shadow prices representing the true scarcity value of inputs and outputs in the Bangladeshi economy) were then substituted for the financial prices to determine economic profitability and reveal underlying patterns of comparative advantage. Only financial profitability was recalculated using the 1998 data.

Financial Profitability

Budgets were developed for two irrigated crops (wheat, boro rice) and for three rain-fed crops (wheat, oilseeds, pulses). Separate sets of budgets were developed for each of the five zones to allow for regional differences in production technology. In the baseline runs, the input-output coefficients corresponded to the most common production technologies (use of animal traction for land preparation and STW for irrigation), and production costs were based on the assumption that both the bullock team and the STW are owned by the farmer (The complete budgets appear in Morris et al. 1997).

Table 2 summarizes the results of the baseline runs of the financial profitability analysis. Irrigated boro rice was clearly the most profitable irrigated crop in 1993, generating significantly higher financial returns to farmer's labor and management, and to land than irrigated wheat in all four zones in which both crops were grown. In absolute terms, the profitability advantage enjoyed by boro rice was extremely large. (The advantage was least pronounced in Zone 3, where yields of boro rice

Figure 2. Map of Bangladesh showing major wheat production zones.

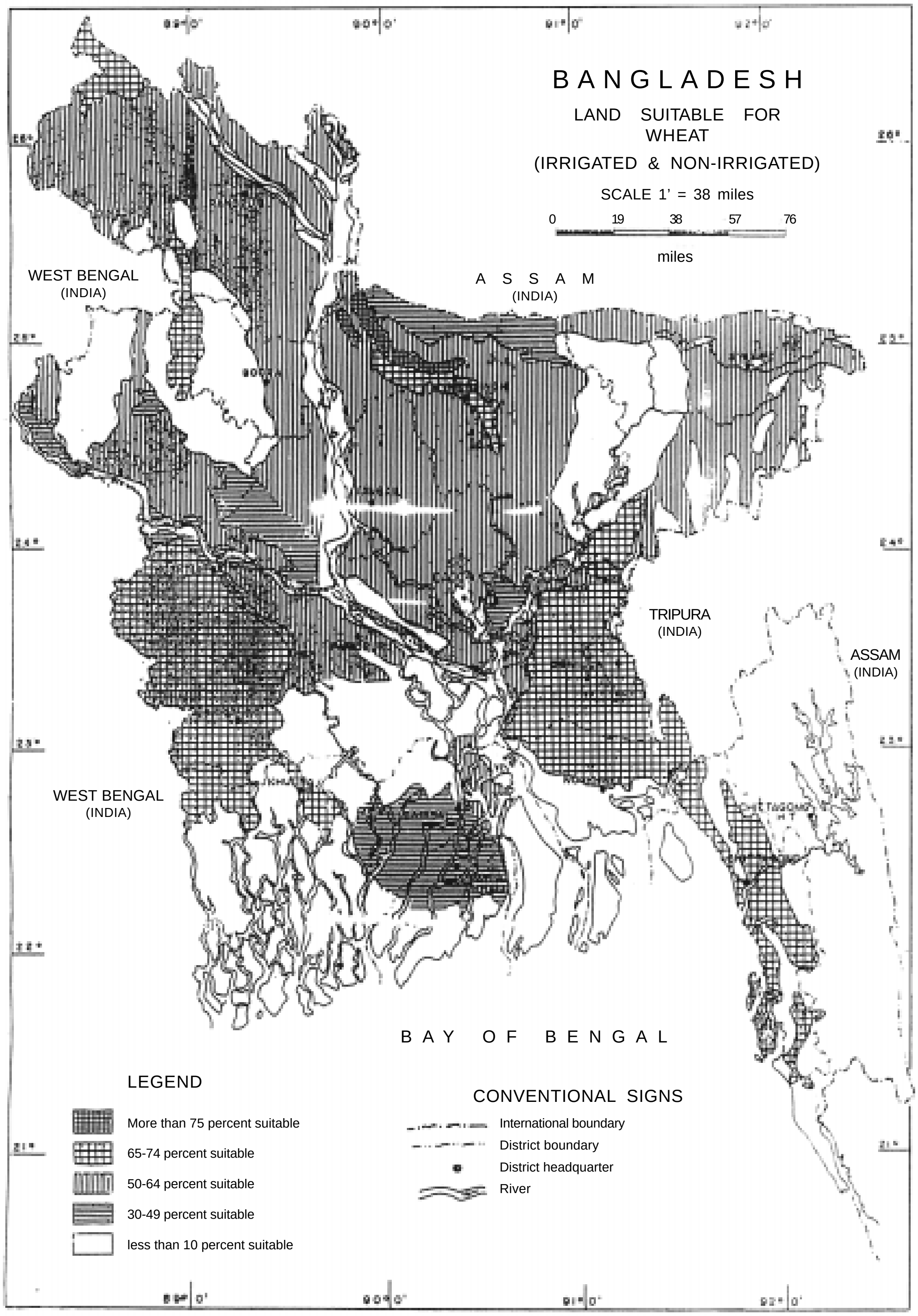


Figure 3. Map of Bangladesh showing the suitability for wheat production based on climate, land type and soil properties.

were relatively low and where labor costs were relatively high.)

Among the non-irrigated crops, the results of the financial profitability analysis varied considerably between zones. Pulses dominated the other rainfed crops in Zones 1, 3, and 4, although the profitability advantage was pronounced only in Zone 3. Oilseeds dominated in Zones 2 and 5 with the advantage particularly prounced in Zone 5. Nowhere did rainfed wheat appear as the most profitable crop, although the financial returns to wheat approached those of at least one of the other crops in most zones.

Overall, these results are consistent with farmers' behavior in irrigated areas in 1993. In financial terms, boro rice was the most profitable irrigated crop, so farmers tended to plant boro rice wherever: (1) land type and soil texture were appropriate, and (2) assured irrigation was available (The only exception was Zone 5, where rainfed oilseeds dominated all other crops, including boro rice). Irrigated wheat was not as profitable in financial terms as boro rice.

Although input costs for boro rice are nearly twice as high as for wheat (primarily because of the much greater irrigation and fertility requirements), higher input costs are more than offset by higher yields. These results confirm the conventional wisdom about the greater financial profitability of boro rice compared to irrigated wheat, and are consistent with the dramatic expansion which has occurred over the past 15 years in the area planted to boro rice.

The results presented in Table 2 are also consistent with farmers' behavior in non-irrigated areas for 1993. In financial terms, the relative profitability of the three rainfed crops varied between zones, with no single crop exhibiting clear dominance across all zones. Pulses and oilseeds generally appeared to be more profitable than wheat, but the relative profitability of pulses and oilseeds compared to wheat was rarely prounced (except in Zone 5). Since markets for oilseeds and pulses tend to be unpredictable, specialising in oilseeds or pulses would have been risky. Also, many households prefer to meet at least a portion of domestic wheat consumption requirements from their own production. In view of these considerations, farmers with non-irrigated land followed a rational strategy in diversifying among the three crops during *rabi* season.

Judging from the results of the financial profitability analysis, it is reasonable to ask: why

Table 2. Financial returns to farmer's management and to land of *rabi* crops (Tk ha^{-1}) using 1993 IFPRI-CIMMYT data.

Zone	Irrigated		Rainfed		
	Wheat	Boro rice	Wheat	Oilseeds	Pulses
	1992/93 prices	L-R trend prices	1992/93 prices	1992/93 prices	1992/93 prices
Zone 1 (NW)	2,111	16,552	2,224	2,125	2,810
Zone 2 (NC)	3,418	17,128	4,993	9,839	4,018
Zone 3 (SC)	4,529	9,566	3,195	3,327	6,541
Zone 4 (SW)	1,696	13,664	3,604	6,631	7,792
Zone 5 (NE)	–	3,515	1,835	17,979	–

Source: Calculated by the authors.

do farmers in Bangladesh grow any wheat at all, if the financial returns to wheat production are everywhere exceeded by the financial returns to production of at least one other crop? Two sets of factors, economic and non-economic, explain why farmers may be acting rationally in choosing to grow wheat despite its apparently lower profitability.

First, wheat production may be economically rational under certain conditions. It is important to remember that the technical coefficients used in the crop budgets are averages calculated across groups of survey respondents. These averages mask considerable variability between individual farm households. For some households, facing slightly different agro-climatic circumstances, endowed with slightly different sets of resources, and/or possessing slightly different management skills, wheat production may be more profitable than production of alternative crops. Evidence of this comes from the survey respondents themselves, 16% of whom indicated that they grow wheat because their land is particularly well suited for wheat production compared to other crops. Even if wheat is not the most profitable alternative, growing wheat may be rational from an economic point of view if farmers face resource constraints which limit their ability to grow other crops. Just over 11% of the survey respondents indicated that the decision to plant wheat in 1992–93 was motivated mainly by the lower investment required in inputs for wheat production. These farmers may have realised that wheat production was not the most profitable alternative, but they simply lacked the resources needed to purchase the inputs and to hire the labour required for other crops.

Second, even when wheat production appears to be unprofitable compared to production of other crops, it is important to remember that farmers' planting decisions are only partly driven by economic considerations. Nearly 40% of the survey respondents stated that the main reason for growing wheat is to lessen exposure to possible food shortages in March and April, the "hungry season" before the boro rice harvest. For these households, the decision to grow wheat is driven by food security concerns, rather than by financial profitability alone.

To determine the effect of recent changes in commodity prices, the profitability of wheat and

Table 3. Financial returns to farmer's management and to land of *rabi* crops (Tk ha^{-1}) using 1998 crop prices.

Zone	Irrigated		Rainfed		
	Wheat	Boro rice	Wheat	Oilseeds	Pulses
	1998 prices	L-R trend prices	1998 prices	1998 prices	1998 prices
Zone 1 (NW)	9,098	16,076	8,559	571	11,655
Zone 2 (NC)	10,896	16,710	11,207	6,150	9,699
Zone 3 (SC)	8,638	13,226	9,057	4,795	17,967
Zone 4 (SW)	14,127	9,003	7,739	2,278	15,482
Zone 5 (NE)	–	–	–	–	–

Source: Calculated by the authors.

competing crops was recalculated for Zones 1–4 using March 1998 prices for wheat, boro rice, oilseeds, and pulses (Table 3). Generally speaking, during the five years since the original IFPRI-CIMMYT study was conducted, the financial profitability of wheat has increased dramatically relative to competing crops. However, the effects have varied by zone. In the north of the country (Zones 1 and 2), the returns to wheat production increased significantly, while the returns to boro rice production remained stable. In the Southwest (Zone 4), a dramatic turnaround occurred in the relative profitability of rice and wheat, with wheat becoming more profitable. Production statistics reflect this change, as many growers in this zone have shifted from boro rice into wheat. The south central part of the country (Zone 3) is the only region in which the profitability of boro rice has increased relative to wheat.

In addition to these changes in the relative profitability of wheat vs. rice, it is interesting to note that the difference in profitability between irrigated and rainfed wheat has decreased in all zones except Zone 4. For Bangladesh as a whole, rainfed wheat now accounts for less than 10% of the area planted to wheat, indicating that increasing numbers of growers are moving into irrigated wheat cultivation.

Non-cereal crops have also been affected by the recent price changes. Generally speaking, the profitability of oilseeds production has declined in all parts of the country due to steep declines registered in oilseeds prices. In contrast, the profitability of pulses has increased spectacularly. This raises an interesting question: why don't more growers produce pulses? Informal surveys indicate that they feel pulses are risky to produce, since they are prone to seasonal diseases and are very sensitive to fluctuations in rainfall. On the other hand, pulses require few inputs compared to cereals; most pulses are simply broadcast and laddered into roughly cultivated soils.

Conclusions and Policy Implications

In the years since Bangladesh achieved independence in 1971, the nation's agricultural sector has undergone a remarkable transformation. With the help of sustained government investment in irrigation infrastructure, input delivery systems, research facilities, and extension services, farmers have achieved a dramatic increase in cereal production. Defying the predictions of many analysts, Bangladesh has transformed itself from perennial food importer to its current position at or near self-sufficiency in rice, the major staple. Production of wheat, the second most important cereal, also increased significantly, although the nation remains a net importer of wheat.

Having achieved one important medium-term goal, Bangladesh policy makers must now decide on a strategy for the longer term. One option would be to continue to promote rice production by maintaining existing policies with the goal of generating exportable surpluses of rice. Another option would be to stabilise rice production at approximately the rate of population growth while encouraging producers to diversify into alternative crops. With the possibility of further area expansion nearly exhausted, it will be difficult to pursue both strategies simultaneously, so difficult choices will have to be made.

One critical issue concerns the future role of wheat. Despite the impressive gains in wheat production realised during the past two decades, supplies of wheat continue to fall well short of demand, and the nation must rely on imports to meet domestic consumption requirements. Some policy makers have argued that with the national rice deficit now largely overcome, the time has come to invest additional resources in wheat research and production support activities. Others have pointed out that such a strategy would not be cost-effective, especially since increased wheat production can come only at the expense of production of competing crops including rice.

This report has reviewed the results of a 1993–94 study that examined the economics of wheat production in Bangladesh and presented updated findings based on 1998 commodity prices. The results presented here indicate that a key finding of the original IFPRI-CIMMYT study is still valid: boro rice often generates greater financial net returns to farmers' labor and management and to land than competing crops. However, during the past five years, the profitability gap has narrowed considerably as a result of changes in wheat and rice prices. Domestic market prices for rice have fallen, while prices of wheat have risen with the result that the relative profitability of wheat has increased.

These findings have several implications for wheat policy. They suggest that wheat production should be promoted, especially in areas unsuited for boro rice production. How might wheat production be promoted? Recent steps taken to reform inputs delivery systems seem to have succeeded in improving the performance of inputs markets and removing distortions on input prices, so the prospective gains from further reforms to input markets appear modest. Producer prices for wheat remain considerably below import parity levels, however, possibly as the result of continuing high levels of food aid and subsidised commercial imports. Since low prices undermine financial incentives to grow wheat, increased production might be promoted through the introduction of measures designed to strengthen wheat producer prices. Based on past experience, efforts to support prices directly are likely to prove excessively costly (e.g. procuring wheat at a support price). A more effective approach might be to restrict imports of wheat food aid in order to generate upward pressure on domestic prices. Indeed, food aid levels have decreased in recent years, which may have contributed to the rise in wheat prices. Additionally, management of wheat imports has improved, with most imports now timed to arrive during the early winter, when any disincentive to wheat prices is potentially the lowest. Since a significant portion of imported wheat food aid is distributed to the poor, however, measures will be needed to ensure that access to food among poor will be protected. One possibility would be to request that food aid donors replace wheat with rice or other cereals. Another possibility is for donors to purchase local wheat or rice and use these staples produced within the country.

Implications for wheat research follow directly from the results of the comparative advantage analysis. Breeding efforts will be needed to develop materials which tolerate late heat. Since irrigated wheat has become predominant over rainfed, research should concentrate on high input and management practices for wheat. Additional research will be needed to shed light on the interactions among the key micro-level factors which determine whether a given plot is suitable for boro rice or not. This is likely to require farm-level surveys involving extensive soil sampling and analysis. Also, it would be particularly useful to work out the break-even yield levels for wheat and boro rice (for different zones, and under alternative production technologies) at which boro rice loses its profitability advantage. Only when the factors determining the relative performance of the two crops are better understood will it be possible to identify research priorities for irrigated wheat.

Finally, it must be stressed that there is a need to improve the process by which improved wheat production technologies are transferred to farmers. The continuing yield gap for wheat, which is considerably larger than the equivalent yield gap for rice, suggests that extension efforts designed to transfer information from researchers to farmers have been less than effective. While low wheat yields can be attributed in part to the lack of incentives to invest more heavily in production inputs, crop management practices for wheat remain deficient in many areas and could be improved by the effective transfer of technologies already "on the shelf". Currently the Government of Bangladesh is considering making the Wheat Research Centre into an institute which will allow it more autonomy in conducting wheat research throughout the wheat-growing areas.

References

Ahmed, R. 1979. Foodgrain supply, distribution, and consumption policies within a dual pricing mechanism: a case study of Bangladesh, IFPRI Research Report No. 8, Washington, DC. IFPRI.

Ahmed, S. M. and **Meisner, C.A.** 1997. Wheat research and development in Bangladesh. pp. 201.

Byerlee, D. and **Morris, M.L.** 1993. Calculating levels of protection: is it always appropriate to use world reference prices based on current trading patterns? World Development, 21–5.

Chowdhury, N. 1992. Rice price environment and extreme poverty in Bangladesh: a comparison between 1970s and 1980s *in* Coping with disaster: the case of Bangladesh. (Dodge, C., Hossain, H. and Abed, F.H., eds.). Dhaka, The University Press Ltd.

Chowdhury, N. 1993a. The structure and conduct of Bangladesh's wheat markets: some emerging insights. Mimeo. Dhaka, Bangladesh Food Policy Project, IFPRI.

Chowdhury, N. 1994a. Credit and Bangladesh's foodgrain market: new evidence on commercialization, credit relations, and effects of credit access. Mimeo. Dhaka, Bangladesh Food Policy Project, IFPRI.

Chowdhury, N. 1994b. Causalities and cost effectiveness of public rice procurement in Bangladesh, paper presented to the seminar on Emerging Food Markets and Food Policy, May 2–4, jointly sponsored by the Government of Bangladesh, IFPRI, and USAID, Dhaka.

Chowdhury, N. and **Farid, N.** 1994. Access to non-cereal food and household food security: concepts, evidence, and implications for food policy, paper presented to the seminar on Emerging Food Markets and Food Policy, May 2–4, jointly sponsored by the Government of Bangladesh, IFPRI, and USAID, Dhaka.

Guisselquist, D. 1992a. Empowering farmers in Bangladesh: trade reforms open door to new technology, paper presented at the Annual Conference of the Association for Economic Development Studies on Bangladesh, November 21–22, World Bank.

Haggblade, S. and **Rahman, M.** 1993. The laws of gravity : a review of rice price movements during the boro season of 1992. Mimeo. Dhaka, Bangladesh Food Policy Project, IFPRI.

Hossain, M. 1987. Fertiliser consumption, pricing and foodgrain production in Bangladesh, *in:* Fertiliser Pricing Policy in Bangladesh, (Stone, B., ed.). Dhaka, IFPRI/BIDS.

Mahmud, W., Rehman, S.H. and **Zohir, S.** 1993. Agricultural growth through crop diversification in Bangladesh. Mimeo. Dhaka, Bangladesh Food Policy Project, IFPRI.

Metzel, J. 1990. (personal communication), member of the World Bank team authoring the study, Bangladesh: Food policy review adjusting to the green revolution. Washington, DC. World Bank.

Morris, M. L., Chowdhury, Nuimuddin and **Meisner, C.A.** 1997. Wheat production in Bangladesh. Technological, economic, and policy issues. IFPRI Research Report. 106, pp. 95.

Morris, M. L., Chowdhury, Nuimuddin and **Meisner**, **C.A.** 1997. Economics of wheat production in Bangladesh. Food Policy 21(6): 541–560.

Morris, M.L. 1989. Determining comparative advantage through DRC analysis: Guidelines emerging from CIMMYT's experience, CIMMYT Economic Paper No. 1, Mexico, D.F., CIMMYT.

Osman, S.R. and **Quasam, M.A.** 1990. Pricing and subsidy policy for Bangladesh Agriculture, Dhaka, BIDS Research Monograph 11.

Rab, A., 1984. Shadow wages of urban and rural unskilled labour in Bangladesh: a preliminary set of estimates. Mimeo. Dhaka, Trade and Industry Reform (TIP) Project.

World Bank, 1992. Bangladesh: Food policy review adjusting to the green revolution. Washington, DC, World Bank.

Socio-economic and Policy Issues Constraining to Sustainable Rice-Wheat System in Bangladesh

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Abstract

Identification of socio-economic and policy factors/issues constraining to sustainable rice-wheat system in Bangladesh is the main focus of this paper. Both macro- and micro-level information taken from primary and secondary sources are used to support the discussion. The issues identified are mainly the concern of policy makers, researchers and the farmers for achieving sustainable food self-sufficiency in the country through rice-wheat production system's sustainability.

Introduction

In Bangladesh, wheat is the second most important cereal after rice. Traditionally, wheat was a minor cereal occupying less than 100,000 ha of cropped land compared to more than nine million ha under rice. The rapid expansion of wheat production in the past in Bangladesh is one of the few spectacular success stories in the development of the agricultural sector of Bangladesh. The growth rates of area, production and yield of wheat increased dramatically since the new CIMMYT bred varieties were introduced in late 1960s (Table 1). These growths are due to the Green Revolution that was initiated through the introduction of breeder seeds by CIMMYT in 1966–67 and by Wheat Research Center (WRC) of BARI in 1974–75 (Swenson et al. 1980). The expansion, however, was halted in early 1980s when with the rapid spread of minor irrigation boro rice grown during the wheat season became the dominant source of expansion of staple food. However, another spurt of expansion of wheat came in early 1990s. In 1992–93, wheat covered about 0.64 million ha with an average yield of 1.84 t ha^{-1}. The area planted to wheat reached 0.75 million ha by 1996–97 with an average yield of 2.4 t ha^{-1}. According to estimates of CIMMYT-Bangladesh, the wheat area reached its peak of 0.80 million ha in 1997–98 (Roy et al. 1998).

The growth in the production of wheat came mainly through area expansion at the expense of minor dry season crops such as oilseeds and pulses. The growth rate of yield has been relatively modest and has stagnated, and the yield has basically stagnated since the mid-1980s. This posed a threat for the system's sustainability and raised many questions that need to be addressed by the biological and social scientists as well as policy makers on an urgent basis. The biological scientists must think about the issue of sustainable high growth rates, which could be maintained by making the system profitable through the development of improved varieties (breeder seeds), improvement of

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Islam, Rafiqul M., Hossain, Mahabub, and **Bhuiyan, S.I.** 1999. Socio-economic and policy issues constraining to sustainable rice-wheat system in Bangladesh. Pages 29–42 *in* Sustaining rice-wheat production systems: socio-economic and policy issues (Pingali, Prabhu L., ed.). Rice-Wheat Consortium Paper Series 5. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

resource management techniques such as nutrient management, pest management, irrigation water management and tillage management. The social scientists, on the other hand, must assess the economic efficiency of alternative management techniques and efficient input-output marketing system, which could help sustaining the rice-wheat production system in Bangladesh.

Rice self-sufficiency in Bangladesh is always fraught with uncertainty as the country suffers from natural calamities. Keeping this view in mind, the government policy makers and experts opined that the emphasis on wheat as a source of sustaining food security needs a careful second look, especially if continued support to wheat would have to come at the expense of support to other crops (Chowdhury et al. 1994). The plausible argument for this is that the wheat crop grown during the dry season which is free from natural calamities. One can argue in favor of boro rice, which could be grown in the dry season throughout Bangladesh as an economically advantageous alternative crop (Table 2). But wheat is suitable only in the northwestern and parts of northeastern Bangladesh where the duration of winter is longer and it is economically advantageous over boro rice where the soils are lighter and the irrigation services are absent or limited. There are, however, some other non-cereal crops like

Table 1. Growth rates of area, production and yield of wheat during 1947/48 to 1965/66, 1947/48 to 1970/71, 1970/71 to 1992/93 and 1993/94 to 1997/98.

Period	Growth rates of wheat (%)		
	Area	Production	Yield
1947/48 to 1965/66	2.54	3.11	0.59
1947/48 to 1970/71	5.59	7.45	1.78
1970/71 to 1992/93	7.30	10.78	3.24
1993/94 to 1997/98	5.40	11.15	5.46
1988/89 to 1992/93	2.60	2.84	0.24

Source: Calculated by the authors based on the information collected from BBS, Ministry of Planning, Dhaka, Bangladesh, and Roy et al. 1998.

Table 2. Comparative advantages of boro rice over wheat cultivation under irrigated condition at different zones of Bangladesh.

Zone	Net return (Tk ha^{-1})			
	Financial analysis		Economic analysis	
	Wheat	Boro rice	Wheat	Boro rice
North-West	2,111	16,552	8,450	17,664
North-Centre	3,418	17,128	10,141	18,453
South-Centre	4,529	9,566	12,736	11,227
South-West	1,696	13,664	7,895	15,015
North-East	NA	3,515	NA	4,591

Source: Morris et al. 1997. NA = data not available

Table 3. Comparative advantages of non-cereal crops over wheat cultivation under non-irrigated condition at different zones of Bangladesh.

Zone	Net return (Tk ha^{-1})					
	Financial analysis			Economic analysis		
	Wheat	Oilseeds	Pulses	Wheat	Oilseeds	Pulses
North-West	2,224	2,125	2,810	7,911	1,043	3,866
North-Centre	4,993	9,839	4,017	9,948	7,527	4,105
South-Centre	3,195	3,327	6,541	7,285	2,852	5,958
South-West	3,604	6,631	7,792	8,322	6,046	7,412
North-East	1,835	17,079	NA	6,625	13,542	NA

Source: Morris et al. 1997. NA = data not available

oilseeds and pulses which have comparative advantages over wheat in certain areas of the country (Table 3). Morris et al. (1997) in their research report on "Wheat Production in Bangladesh: Technical, Economic and Policy Issues" carried out sensitivity analysis to see the effect of changes in some parameters on profitability, which are the main concern of government policy makers. The present study, on the other hand, looked into the issues which are of direct concern to both researchers and farmers. We postulate that while policy support is needed to extend the existing technologies in the recommendation domains, accelerated research to address the constraints of growth in productivity and efficiency could help extending the recommendation domains.

This paper attempts to look into the socio-economic and policy factors that constrain development of sustainable rice-wheat systems in Bangladesh.

Socio-economic Problems Focus on Sustainable Rice-Wheat System

Profitability effect of changing yield: sensitivity analysis

The discussions in the following sections highlight how the researchers and farmers could make wheat cultivation more profitable and the production systems more sustainable in both the irrigated and rainfed environments.

Tables 4 and 5 show the frontier yields that would make wheat financially and economically more profitable compared to boro rice and *rabi* crops in different zones of Bangladesh. A sensitivity analysis was done to arrive at the results. In terms of financial profitability under irrigated situation, the required future wheat yield at different zones would have to increase by 35–135% over the current yield (Table 4) to be able to out-perform boro rice. For economic profitability under the same situation, the required future wheat yield would have to increase by 43–55% over the current yield to match boro rice. The researchers will have to develop wheat varieties and crop management systems which could give yields ranging from 3.59–4.53 t ha^{-1} for making wheat financially more profitable and 2.98–3.17 t ha^{-1} for making it, economically, a more profitable crop.

Experimental results from Wheat Research Center (WRC) in Dinajpur suggest that the currently available wheat varieties have the potential to make it profitable compared to the competitive boro rice. To achieve the potential yield at the farmers' fields, improvements in the

Table 4. Required frontier yield of wheat to rank it first in terms of profitability compared to irrigated boro rice cultivation in Bangladesh.

Zone	Financial profitability			Economic profitability		
	Current yield (kg ha^{-1})	Required yield (kg ha^{-1})	% required yield increase/ decrease	Current yield (kg ha^{-1})	Required yield (kg ha^{-1})	% required yield increase /decrease
North-West	1,927	4,529	135	1,927	2,979	55
North-Centre	2,211	4,563	106	2,211	3,171	43
South-Centre	2,651	3,592	35	2,651	2,561	–3
South-West	1,846	3,976	115	1,846	2,662	44
North-East	NA			NA		

Source: Calculated by authors based on yield data used by Morris et al. 1997. NA = data not available

level of inputs use, specially seed quality and fertilizers amounts, and improved management practices in land preparation (i.e., zero or minimum tillage), sowing/planting date, irrigation management, and pest management would be required. Improved management could save about 85% of total yield loss (Roy et al. 1998).

In rainfed situations, the wheat crop is competitive to oilseeds and pulses. The wheat yield sensitivity analysis was done with these crops and the results are shown in Table 5. The existing wheat yields in the farmers' fields in different zones except northeast zone is quite satisfactory in terms of economic profitability. But for making wheat production financially as profitable as the oilseed and pulse crops in the northeast zone, the yield would have to be raised by 1.88–4.11 t ha^{-1}, which is 6–151% higher than the farmers' current yield.

Relative output price effect: regression estimate

A multi-variate regression was used to estimate the factors associated with wheat area cultivated

Table 5. Required frontier yield of wheat to rank it first in terms of profitability compared to best alternative non-irrigated *rabi* crops (oilseeds and pulses) cultivation in Bangladesh.

Zone	Financial profitability				Economic profitability			
	Current yield (kg ha^{-1})	Required yield (kg ha^{-1})	% required yield increase	Best alternative crops	Current yield (kg ha^{-1})	Required yield (kg ha^{-1})	% required yield increase	Best alternative crops
North-West	1,769	1,876	6	pulses	1,769	1,301	–26	pulses
North-Centre	1,707	2,523	48	oilseeds	1,707	1,430	–16	oilseeds
South-Centre	1,393	1,983	42	pulses	1,393	1,238	–11	pulses
South-West	1,581	2,270	44	pulses	1,581	1,478	–7	pulses
North-East	1,636	4,108	151	oilseeds	1,636	2,412	47	oilseeds

Source: Calculated by authors based on yield data used by Morris et al. 1997.

Table 6. Regression estimates of factors associated with wheat area in Bangladesh, 1971–97.

Factors	Estimated coefficients	t-statistic
Intercept	–469.3507^{ns}	–1.1552
Aman area	–0.0074^{ns}	–0.1169
Aus area	0.0446^{ns}	0.7827
Boro area	0.1024**	1.5943
Oilseeds area	1.3294*	6.3862
Pulse area	–0.1373**	–1.5732
Relative price ratio	102.7321^{ns}	0.3145

Notes: R^2 = 0.94, F-statistic = 46.7617, Log likelihood = -133.2772, Durbin-Watson = 1.8981,
* P<= 0.01. ** P<= 0.015. ns = not significant.

during 1971 to 1997. The estimated model has good explanatory power as indicated by its high R^2= 0.94 value. The F-statistic indicated that the relationship between wheat area and the explanatory variables are significant at 1% level (Table 6).

Among the explanatory variables, areas grown to boro rice, oilseeds, and pulses were found to be significantly related with wheat area. Wheat area was expected to be negatively associated with boro rice and oilseed areas, but it was found positive in the regression analysis, which is possibly because of the favorable weather during 1993–1998 and the want of food security concerns encouraged farmers to grow more wheat in their fields. The positive association between wheat area and relative price ratio of wheat to rice indicate that the increase in the relative price of wheat over rice in the early 1990s might have influenced farmers to increase their wheat acreage, during the recent past. But the variable was not found to be statistically significant.

The increased wheat price provided incentive to farmers and ensured its production substantially during the past years. This has also encouraged farmers to grow more wheat, which resulted to positive relation between wheat and boro areas. Any farm price incentive to wheat and rice growers would help increasing its area in the future production plan of rice-wheat system. The assured irrigation to boro rice fields and price incentive to wheat and rice growers could make a positive link between wheat and boro rice. The existing food grain procurement setup of the country should work effectively and be liable to the people concerns. Involvement of NGOs and private sector in food grain procurement would create a social environment as well as a platform for competition amongst the buyers, and as a result the growers will get remunerative price of their products.

Lack of draft power for tillage management

In rice-wheat system, wheat is grown in two major cropping sequences: (i) Aus/Jute-fallow-wheat and (ii) Fallow-T.Aman-wheat. Wheat cultivation under each of the above two patterns is constrained by labor and draft power scarcity, which delays the establishment of the wheat crop. Planting of T. Aman rice crop particularly in the light textured soils, which are preferred by the farmers as suitable land for wheat cultivation, occurs during July-August and harvested in the first week of November leaving a short turn-around time of about 7–10 days for timely establishment of wheat on November 15 after T. Aman. Sowing of wheat beyond this date would drastically reduce the yield of about 1.3% per day. So, cultivation of either short-duration T. Aman rice varieties or planting of this crop at about 15 days earlier, i.e., on or before June 15, could increase turn-around time between T. Aman-wheat cropping system, which could help farmers to increase their wheat area. A preliminary survey at Chuadanga, Gangni and Jhenaideh in Bangladesh showed that the availability of family labor is only 0.72 labor/ha and draft power is about 1.40 animal/ha, which are a constraining factor for timely land preparation and crop establishment (Islam et al. 1992). This constraining factor has raised the issue of zero and/or minimum tillage practice in wheat cultivation. Studies at Comilla and Rajshahi showed that zero tillage, minimum tillage and conventional tillage give similar grain yield of T. Aman rice (Table 7). The prevalent practice in T. Aman rice cultivation is to grow the crop on puddled soil. Puddling is done by using traditional/country plow which helps to form soil pan and reduce the yield of succeeding wheat crop. A contrary conclusion was drawn in the study on the effect of tillage in 1992, which indicated that the grain and straw yield of wheat are not affected by tillage methods (Table 8). This finding was derived from a researcher's controlled experiment. Detailed investigations of the biophysical and socioeconomic implications of different tillage systems for the long-term productivity and sustainability of rice-wheat system at different agroecoregions are needed.

Water resource management policy

In Bangladesh, more than 90% of all developed water resources are used for agricultural purposes and about 95% of them are used for cereal production. Currently, about 40% of all agricultural lands have access to irrigation water. Nearly 90% of all irrigation water comes from groundwater sources and the remaining 10% use surface water. In many areas, the limits of safe withdrawal of groundwater have been crossed. Government's recent privatization policy and scrapping of taxes on equipment import have encouraged this process. It is generally believed that the scope of further expansion of groundwater-based irrigation facilities is very limited in Bangladesh. But the true extent of groundwater irrigation i.e., sustainable in the long-term economically, socially, and environmentally is yet to be determined (Bhuiyan 1995). It is, however, clear that for sustainable increases in irrigation facilities that are essential for increasing cereal production in the foreseeable future, groundwater resources must be managed more scientifically and greater use of surface water resources must be encouraged through appropriate policies. Continuation of the current policy of allowing indiscriminate proliferation of tubewells can not be sustained.

Table 7. Effect of tillage on yield of T. Aman, 1990.

Treatment	Rajshahi (t ha^{-1})		Comilla (t ha^{-1})	
	Grain	Straw	Grain	Straw
Zero tillage	3.5	3.0	3.4	2.7
Minimum tillage (dry opening)	3.3	3.3	3.7	3.8
Conventional puddling	3.4	3.3	3.9	3.7
LSD(0.05)	NS		NS	

Source: RFSD, BRRI, Gazipur. NS = Not significant at 5% level.

In the past, estimates of potentially irrigable areas that could be supported by groundwater were based mostly on the concept of "hydrologically safe" withdrawals from the aquifers, which is aimed at preventing irreversible lowering of the water table. Experience has indicated that issues of the environment, water quality, social equity, etc. must be adequately considered in planning groundwater development and use as a common property resource (Bhuiyan 1995). In some areas, intense competitions between DTW use for boro rice cultivation and shallow hand pumps used for lifting drinking water have created drinking water crisis with serious negative impact on the poor in the rural society (Sadeque 1996).

There are increasing concerns about the quality of groundwater in Bangladesh. It has been recently reported that in 70% of the 64 districts, most of which are in the Gangetic Flood-plains, there are high concentrations of arsenic in groundwater that is used by people for irrigation and drinking. In some areas, many rural people have developed serious skin diseases from drinking the water and from extended contact with it in the field. It is believed that the arsenic content has increased to dangerous proportions in these areas due to excessive lowering of the water table in the dry season for irrigating boro rice.

Rice production in the dry season consumes much more water than does wheat. Therefore, in areas where the groundwater resource is limited and/or where arsenic problem in groundwater is already severe or potentially severe, substitution of boro rice culture with wheat culture should be encouraged through appropriate policy and incentive measures. In larger irrigation systems, significant amount of water can be saved and water productivity substantially increased by growing rice as direct-seeding crop as opposed to transplanted crop (Bhuiyan et al. 1995). Combining direct-seeding and choice of early-maturing rice variety in the Aman season, the rice system can benefit from reduced irrigation water and labor (labor for transplanting) expenses, and the subsequent wheat crop from timely establishment. Many wheat fields in Bangladesh are now established too late for the season and suffer consequent yield reductions. One main reason for this delay is that the rice crop is harvested late.

A group meeting of the members of Rice-Wheat Consortium held in August 1995 in Bangladesh has identified four problem areas that constitute threats to the productivity and sustainability of rice-wheat systems in the Indo-Gangetic plains of South Asia i.e., Bangladesh, India, Nepal and Pakistan. One of them is the water resource management, which comprises issues of water management at the farm level, irrigation system level, and macro-policy level.

Table 8. Effect of tillage on yield of wheat at Chuadanga in 1992.

Tillage	Grain (t ha^{-1})	Straw (t ha^{-1})
Minimum tillage	3.31	4.19
Conventional tillage	3.02	4.17
SE	0.23	0.27
Significance level (0.05)	NS	NS
CV(%)	17.06	15.70

Source: Elahi et al. 1995. RFSD, BRRI, Gazipur. NS = Not significant at 5% level.

Water issues need increasing attention as the available water resource for agricultural use is getting scarce day by day.

Very recently, the introduction of macro-economic policies regarding government's withdrawal of subsidies from irrigation, imposition of higher energy prices and privatization policy of irrigation equipment led to higher irrigation fees imposed by those who invested on groundwater development on the other small farmer users. Consequently, small farmers' profitability and sustainability of rice-wheat systems have been affected. Studies show that though wheat requires much less irrigation water than rice i.e., 3-4 times lesser than rice, it can't tolerate water stress at critical growth stages. Water stress at these stages reduces wheat yield significantly (Islam et al. 1995). Moisture stress at the crown root initiation (CRI) and booting stages upto 0.8 bar tension may cause yield reduction of 37–60%. Around 50% depletion of available soil moisture (or 0.50 bar tension) was found optimum for wheat irrigation. When shallow water table is within 2 m in heavy soil and 1 m in medium and light soils, wheat may not require any irrigation.

In Bangladesh, about 46% of wheat fields were irrigated during 1990–91. A farm-level survey at Chuadanga, Gangni and Jhenaidah in Bangladesh showed that farmers irrigated their wheat crop 2–3 times depending upon their field observations. They used water from deep tube wells (DTWs), shallow tubewells (STWs) and traditional sources. Tables 9 and 10 show the distribution of sample farmers according to their accessibility to irrigation water and by source. Majority farmers have access to irrigation water from modern means such as DTWs and STWs, but they do not own the irrigation equipment. They are using water from some one else's pump on payment basis. A DTW may be co-owned by a group of farmers. A STW is usually owned by a single farmer who forms a farmers' society around his farm area to sell water. A farmer may

Table 9. Distribution of farmers having accessibility to irrigation water by sources, 1992.

Accessibility to irrigation water	Chuadanga (% farmers)	Gangni (% farmers)	Jhenaidah (% farmers)	All sites (% farmers)
DTW	58	89	100	82
STW	22	7	–	10
Trad. method	20	4	–	8

Table 10. Distribution of farmers owning irrigation pump, 1992.

	% farmers			
	Chuadanga	Gangni	Jhenaidah	All sites
Farmers owned irrigation pump				
DTW	16	36	56	36
STW	–	11	–	4
Others	–	4	–	1
Farmers don't own irrigation pump	84	49	44	59

Source: Islam, 1992, Agril. Economics Division, BRRI, Gazipur.

be a member of more than one irrigation societies. Other studies have shown that most farmers who do not have their own irrigation equipment complain about various problems they face in their irrigation activities, which ultimately affects the productivity of rice-wheat systems. In DTW and canal-based surface irrigation systems, problems of under-utilization of the available water resource, and canal management are common.

Lack of knowledge about soil nutrient management

Numerous cropping patterns are being practiced by farmers in Bangladesh; the choice is made depending upon the agro-ecological conditions and availability of irrigation facilities (Bhuiyan 1995). These cropping patterns are essentially rice-based, such as fallow-rice-wheat, rice-fallow-wheat and rice-rice-wheat. As multiple crops are grown on the same piece of land sequentially within the same year without much reprieve, the soil nutrient is affected constantly, which ultimately affects crop productivity and sustainability of intensive agricultural practices.

A survey in 1992 in Dinajpur area revealed that the wheat yield alone decreased by 15% and that it was due to the farmers' inability to afford the recommended dose of fertilizer. Many of the farmers raised sustainability the most pressing issue in rice-wheat systems as the increase of cropping intensity coupled with minimum use of fertilizers is causing erosion of both macro- and micro- nutrients from soil (Saunders 1990, Badaruddin 1989, Ahmed and Elias 1986). Serious soil-nutrient erosion is commonly found in the rice-wheat systems. Rice is grown in puddled soil which creates a 10 to 25 cm thick hardpan at 10 to 15 cm below the soil surface. These plow pans restrict root systems development of both rice and wheat. As a result, the plant has to depend upon the limited nutrients available within the top 10 to 15 cm soil. Therefore, biological and physical science research must find ways to expand the scope of plant-nutrient availability in order to increase the efficiency in nutrient uptake by the plant.

Demonstrations for wheat yield maximization in farmers' fields with recommended levels of N, P, K, S and Zn, B and Mn depending on location, plus 7–10 t ha^{-1} of good quality cow dung and treated seeds yielded 4.05–6.25 t ha^{-1} indicated that fertility level is a major yield constraint in the farmers' fields (Razzaque et al. 1990). Recommended fertilizer application with optimum planting date contributes about 76% of the yield increase. Most Bangladeshi farmers suffer from socio-economic problems such as lack of technical know-how, initial investment capital, high input price, input non-availability, low market price of their produce, etc. All these problems are linked with the government input-output price and market policies. Many social thinkers have raised questions about the existing fertilizer distribution policy and considered it as a threat to country's sustainable agriculture.

High input and low output price

A recent household survey in the rice-wheat system at Chuadanga revealed that of the socio-economic problems, the low output price ranked top, which was followed by high input cost, shortage of draft power and labor, non-availability of inputs in time, insufficient extension services, lack of credit, high price of fuel, land tenancy, and insufficient irrigation water. These problems were identified based on clear evidences, field observations and discussions with farmers. Two ranking criteria used to prioritize the problems are: (i) percent farmers affected, and (ii) frequency of

Table 11. Matrix ranking of socio-economic constraints to rice-wheat systems sustainability at Chuadanga in Bangladesh.

Constraints	% farmers affected	Frequency × % farmers affected	Cumulative value	Rank
Low output price	84.6	119.3	203.9	1
High input cost	80.8	103.9	184.7	2
Lack of draft power	80.8	96.2	177.0	3
Inputs non-availability	73.1	77.0	150.1	4
Shortage of labor	65.4	65.4	130.8	5
Lack of extension service	46.2	80.9	127.1	6
Non-availability of credit	38.5	65.8	104.3	7
Non-availability of fuel	46.2	50.1	96.3	8
Land tenancy	38.5	36.2	74.7	9
Irrigation water	19.2	23.1	42.3	10

Source: Primary level information collected by the authors.

occurrence. Higher value of the cumulative score means higher priority. In all ten problems were identified and ranked, and are shown in Table 11. Farmers argued that high input and low output price hindered them from increasing their wheat area. Because farming, now-a-days, is not only for maintaining the subsistence level, but it is now being commercialized. Every farm operates to earn maximum profit. High input and low output prices many times generate minimum margin. This minimum margin is, thus, attract farmers to look for the best alternative cropping practices. An earlier finding (Morris et al. 1997) suggests that boro rice is competing with wheat as it generates greater financial net returns in irrigated condition. But the profitability of boro rice production is declining now-a-days as its yield is falling. The wheat production, on the other hand, showed its relative profitability when inputs and outputs are assigned economic prices. The government in this case is only the implementing authority to ensure output price through effective procurement policy by appointing government, NGOs and private agencies at the right time and places. For estimating the procurement price, the government should monitor cost-benefit analysis so that it can take right decision about the procurement price.

Input distribution and marketing

Non-profitability or low-profitability of wheat and high cost requirement of boro rice cultivation encourage farmers to shift from wheat and boro rice to cultivation of maize, oilseeds and pulses in the dry season. Farming in Bangladesh is gradually being commercialized with the application of modern inputs like modern variety (MV) seeds, chemical fertilizers, irrigation water, pesticides, etc. MVs involve the use of large amounts of purchased inputs whereas traditional agriculture uses inputs like cowdung and other organic matter available within the farm. Modernization of agriculture involves higher investment as well as more risks, such as physical loss of crop due to natural calamities and price risk. Thus, markets and marketing policies play a crucial role in modernizing subsistence agriculture. A successful production program requires, apart from MV seeds and improved production technologies, a satisfactory delivery system of inputs and a positive but effective pricing and marketing policies for the output (Hossain 1991).

The following are the key concerns expressed by farmers that need the attention of the national policy makers.

(i) Inadequate seed storage facilities

(ii) Non-availability of inputs in time (seeds and fertilizers)

(iii) Unnecessary delay in disbursing institutional credit

(iv) Absence of support price

(v) Unstable marketing systems

(vi) Inefficient input distribution system, and

(vii) Ineffective food grain procurement and distribution during crisis periods

Lack of knowledge about pest management

With the expansion of MV adoption, pest management from seed to seed is getting increasing importance. Diseases are a serious problem for both rice and wheat in Bangladesh. So far, 31 diseases of rice have been recorded (Mian et al. 1987). Among them, 20 are caused by fungi, 6 by nematodes, 3 by bacteria, and 2 by virus and mycoplasma. The most important diseases in rice are leaf blight, sheath blight, tungro, ufra, sheath rot, leaf scald, blast, brown spot, bacterial leaf streak, stem rot, bakanae, seedling blight and root knot. About 15-18% rice yield is considered lost annually due to these diseases (Mian 1985).

Wheat suffers from 17 diseases, 12 of which are caused by fungus, 2 by virus, 2 by nematodes, and 1 by bacterium. The important diseases in wheat are leaf rust, leaf spot complex, seedling blight, loose smut, black point and foot- and root-rot. About 10% yield reduction due to diseases was reported, but on a susceptible variety like Morocco, leaf rust may cause as high as 58% yield loss (Mian 1985).

However, studies on seed treatment, soil incorporation with insecticide, and foliar application resulted to a significant increase in productivity of wheat. Soil treatment with furadan at 0.6 kg ai ha^{-1} has increased yield by 28% at the optimum seeding date and 108% at later seeding dates. Nemacur at 1.0 kg ai ha^{-1} has increased yield by a coincidental 28% at the optinum seeding date. Seed treatment using Vitavax–200 has increased yield of wheat by 12% (Razzaque et al. 1991). Though the pest management has increased yield remarkably, but the increasing cost of pesticides and non-availability of pesticides and spray machines cause delay in farmers' spraying and under application of pesticides. In the past, little effort was given to studying farmers' perceptions, knowledge, attitudes and practices about pest management. Farmers generally cannot differentiate between pests and predators. They are unskilled in using knowledge-based pest management techniques in an economically optimal manner. Many times they overuse pesticides and apply them at wrong times without considering economic threshold level, which result in economic loss. As a result, the sustainable productivity of rice-wheat system is being threatened. So, the determination of economically optimum-use level is the present focus of the social sciences group. Moreover, the after effect of using pesticides on environments and human health is a major concern of the environmentalists, which needs due attention by both researchers and policy makers.

Land tenancy and presence of "dadon"

About 60% of rural farm families in Bangladesh are landless. A large portion of them has to depend on land cultivated on share basis. The marginal, small and even the medium farmers are also cultivating a portion of their land on share basis. Due to the increasing percentage of landlessness, the competition amongst the share-croppers has increased, which creates an environment for the land owners not to provide share of inputs to the share-croppers. The share-croppers and/or tenant farmers have to cultivate even with zero input share from the land owners. The prevailing input-output sharing arrangements between the tenant and the owner farmers discourage them to cultivate crops, which are input intensive. Many times the share-croppers and/or tenant farmers have to seek money from village money lenders (*mohajan*) with an agreement to sell the harvest to them at a lower price. This unfair system ("dadon") discourages them from cultivating crops like rice and wheat, which need significant input costs. The recent NGOs set-up in the rural areas have extended their help to rural poor. However, it is very rare that the NGOs provide loan for crop cultivation. Because their recovery system, i.e., weekly payment, does not encourage poor farmers to receive loan against crop cultivation. Rather, they receive loan against petty business and purchasing of rickshaw etc., so that they could have daily income-flow and could easily repay their weekly instalment. Moreover, the interest rate on the loan from this source is very high (22–30%) compared to bank loan (11%). Thus, rural banking services, having easy access by farmers, could help improve and sustain the rice-wheat system in Bangladesh.

Conclusions and Policy Implications

The socio-economic problems, which are mainly concerned with the national policy issues for sustaining the production of food grains (i.e., rice and wheat) are not being properly addressed by policy makers. Such problems include distribution and marketing of inputs and outputs. Recent privatization policy about fertilizer input distribution i.e., fertilizer distribution through private dealers, seems to work for their self-help rather than the benefit of the farmers. The selling of single-super-phosphate (SSP) in the name of triple-super-phosphate (TSP) is a common practice in our situation, which resulted in low productivity. The dealers should somehow be liable to the government. The government, in this case, could utilize its big set-up like Bangladesh Agricultural Development Corporation (BADC) and Agricultural Extension Department (DAE), so that the government could directly charge to them for any failure in this regard. The BADC and DAE will be solely responsible to make the fertilizer available from millgate to farmgate at the government price. Similar technique could also be followed for other inputs like pesticides. The two departments should be given authority to appoint and/or cancel dealership for any anomaly regarding input marketing. Both these two departments could take program for quality seed production through contract growers and distribute thereof at the government price. Low output price is an another problem, which needs to be addressed by policy makers. Low-output price definitely helps the consumers, who are the majority of rural low-income group. On the other hand, high-output price could give incentives to the producers that could help increase and sustain the systems' productivity. So, to please both the producers and consumers, it is a challenging task for the policy makers. One way to solve this type of problem is to maintain stability of consumers' price within their income limits by introducing proper distribution systems through food rationing. The producers' interest, on the other hand, could be safeguarded either by introducing cost-effective input-output price policy or by introducing low-cost technology through public investment in research, extension and irrigation facilities. For introducing cost-effective input-output price policy, a constant farm-level survey of cost-benefit analysis through the establishment of farm planning, monitoring and evaluation cell at the thana level could be done. The present privatization policy in irrigation has no doubt increased the number of shallow tube wells (STWs), but it has created a number of socio-economic repercussions. The small and marginal farmers who cannot afford to buy STWs cannot also afford to allow and maintain canal from public sector irrigation project passing through their land. STWs are certainly more sustainable and socially beneficial when they are used by small-holding farmers in a group, without any exploitation by the owner. However, many of the privately-owned STWs are underutilized. To ensure the application of fertilizers at right time and in a balanced dose, farmers could be provided with agricultural loan on easy terms and conditions. Rural banking facilities with proper supervision could be extended to help the actual growers.

References

Ahmed, M. and **Elias**, **S.M.** 1986. Socio-economic systems of wheat cultivation in Bangladesh: proceedings of the third national wheat training workshop, August 4–5, BRRI-WRC and CIMMYT/CIDA wheat program, Dhaka, Bangladesh.

Badaruddin, M. 1989. Annual research report on crop mangement of wheat. Paper presented at the central review workshop, Joydebpur, Gazipur, Bangladesh, BARI.

Badaruddin, M. and **Razzaque**, **M.A.** 1995. Major growers defined reaearch issues in rice-wheat systems: proceedings of the workshop on sustainability of rice-wheat systems in Bangladesh. Nashipur, Dinajpur, Bangladesh, WRC, BARI.

Badaruddin, M., Saunders, D.A., Siddique, A.B., Hossain, M.A., Ahmed, M.M., Rahman, M.M. and **Parveen**, **S.** 1993. Determining yield constraints for wheat production in Bangladesh. Joydebpur, Gazipur, Bangladesh, WRC, BARI.

Bhuiyan, N.I. 1995. Long-term soil fertility management in rice-wheat system: proceedings of the workshop on sustainability of rice-wheat systems in Bangladesh. WRC, BARI, Nashipur, Dinajpur, Bangladesh.

Bhuiyan, S.I., Bhuiyan, **Sattar, M.A.** and **Khan, M.A.K.** 1995. Improving water use efficiency in rice irrigation through wet-seeding. Irrigation Science (1995) 16:1–8.

BRRI. 1992. Annual Report for 1991. BRRI, Gazipur, Bangladesh.

Chowdhury, N.U, Morris, M. and **Meisner, C.A.,** 1994. Comparative advantage of wheat in Bangladesh, IFPRI, Dhaka, Bangladesh.

GOB, 1996. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka, Bangladesh.

Hossain, M., 1991. Agriculture in Bangladesh: performance, problems and prospects. Red Crescent Building, 114, Motijheel C/A, Dhaka. The University Press Ltd.

Islam, M.R. and **Mustafi, B.A.A.** 1998. Participatory rural appraisal (PRA) report for T. Aman season under rice-wheat system at Chuadanga. Agril. Econ. Division, BRRI, Bangladesh.

Islam, M.R., Ahmed, N.U., Bhuiyan, A.M., Alam, M.M., Ghani, M.U., Quddus, M.A. and **Islam, M.T.** 1992. Methods of measuring sustainability through farmer monitoring: Application to the rice-wheat cropping pattern in South Asia: proceedings of the workshop, May 6–9, Kathmandu, Nepal.

Islam, N.I. and **Rashid, M.A.** 1995. Water mangement in rice-wheat system: proceedings of the workshop of RW system in Bangladesh.

Mian, S.A. 1985. Disease problem of cereal crops in Bangladesh. A paper presented at 1st biennial conference of Bangladesh Phytopathological Society held at BARI, Joydebpur, Gazipur.

Mian, S.A, and **Shahjahan, A.K.M.** 1987. Identification of rice diseases in field and in control. Bull. No.86, Joydebpur, BRRI.

Morris, Michael L., Chowdhury, Nuimuddin, and **Meisner, Craig A.,** 1997. Wheat production in Bangladesh: technical, economic and policy issues. Research Report No. 106, Washington, DC., IFPRI.

Razzaque, M.A and **Hossain, A.B.S.** 1990. The wheat development program in Bangladesh: proceedings of the workshop on sustainability of rice-wheat systems in Bangladesh. Nashipur, Dinajpur. WRC, BARI.

Razzaque, M.A and **Hossain, S.** 1991. The wheat development program in Bangladesh. Joydebpur, Gazipur, Bangladesh. WRC, BARI.

Roy, Indrajit and **Kabir, Wais** 1998. Wheat the alternative staple. Weekend Independent, 24 April 1998, Dhaka, Bangladesh.

Sadeque, S.Z. 1996. Nature's bounty or scarce commodity - competition and consensus over groundwater use in rural Bangladesh. Paper presented at the annual conference, June 5–8, 1996, International Association for the Study of Common Property, Univ. of California, Berkeley.

Saunders, D.A. 1990. Report of an on-farm survey, Dinajpur District: farmers practices and problems and their implications, Nashipur, Dinajpur (Monograph). WRC, BARI.

Shahabuddin, Q. and **Zohir, S.** 1995. Projection and policy implication of medium and long-term rice supply and demand: country report for Bangladesh, BIDS, Dhaka.

Swenson, C.G., Ahmed, J., Alam, Q.M., Barman, S.C., Haque, A.K.M.H., Hussain, M.S. and **Sikder, F.S.** 1980. A survey of the economics and agronomy of wheat production in Jessore and Pabna Districts. BARI, Joydebpur, Gazipur, Bangladesh.

Globalization of Agriculture and its Impact on Rice-Wheat System in the Indo-Gangetic Plains

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Abstract

What would happen to wheat-rice cultivation in the Indo-Gangetic plains in the face of globalization of agriculture as agreed under the Uruguay Round Agreement or likely to be taken up in the millennium round? This paper examines this question through estimation of effective incentives and resource use efficiency in wheat- rice cultivation through indicators such as effective rates of protection and domestic resource cost. These are compared with the producers' subsidy equivalents of wheat and rice in some selected countries in the world. This comparison helps to see where the wheat-rice cultivation of the Indo-Gangetic plains would stand if distortions (subsidies) in the production of wheat and rice in major producing/consuming countries in the world are eliminated and international trade in wheat and rice is freed from all controls. The results indicate that under such a scenario cultivators of wheat and rice in the Indo-Gangetic plains are likely to gain significantly. Given this possibility, the major concern is that of sustainability of the rice-wheat system within the existing water resources of the states in the Indo-Gangetic belt.

Background

The Uruguay Round Agreement (URA) of the General Agreement on Tariffs and Trade (GATT) signed on April 15, 1994 at Marrakesh made a beginning towards building a global system of trade in agriculture that is less distorted than what existed at that time. The World Trade Organization (WTO) saw that the Agreement on Agriculture (AOA) gets implemented starting with January 1, 1995. It is well-known that AOA has three main clauses: increasing market access through tariffication of quantitative restrictions of imports and exports; reduction of domestic support to agriculture and reduction of export subsidies. It is equally well-known that although URA made a good beginning by incorporating agriculture into its fold, but it could not make any significant change in the existing distortions due to 'dirty tariffication' followed by many developed countries. However, the URA has a built in clause: that AOA must be reviewed by the end of the current millennium. Accordingly, Ministerial meeting is proposed in Seattle in November-December 1999 to see what progress has been made with respect to AOA, besides several other issues. It is expected that in the new millennium round of WTO, distortions in world agriculture – both production and trade – would be substantially controlled. Market access is likely to increase, domestic support to agriculture is likely to be cut down significantly and export subsidies are likely to be almost abolished. How much progress is really made in this direction during the millennium round, only time will tell. But for a country like India, or for that matter for all countries, it is imperative to examine the efficiency status of their agriculture, especially its principal crops and see what may

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happen to them once agriculture globalization takes place in true sense. In India, looking at domestic economic reforms, which do aspire to globalize the economy, it appears that globalization of agriculture is only a matter of time. It would take place, though with lot of hiccups.

It is with this background in mind that this paper examines the status of effective incentives and efficiency of two of its principal crops – rice and wheat in the Indo-Gangetic plains. This would provide an idea of what is likely to happen to these two crops once trade is liberalized and domestic prices catch up to the world prices. There are two ways in which this can be examined: first by assuming that India liberalizes its agriculture but the rest of world agriculture remains distorted, and second, by assuming that the distortion in world agriculture, especially the domestic support in developed country is contained, reduced or eliminated. We first work out the incentive and efficiency status of Indian wheat and rice under the first assumption and then conjuncture on the basis of the second assumption.

It is well-known that in the Indian Gangetic plains, there has been a spectacular growth of wheat and rice during the last three decades as a result of Green Revolution in India. But despite this, wheat and rice sectors remained subjected to wide-ranging controls in the name of food security. There is still a levy of 75% on the millers of rice in Punjab and Haryana. Imports and exports of wheat and rice on private account remain either banned or tightly regulated by the Government of India, with a notable exception of basmati exports. There are stocking limits on private traders to hold wheat and rice beyond a specified quantity under the Essential Commodities Act, which sometimes is also used to restrict inter-state movement of grains. There is a ban on future trading in these crops. Rice milling, until recently, was reserved for the small-scale sector. The support/ procurement prices of wheat and rice are decided by supposedly taking into account a number of factors ranging from their cost of production to terms of trade between agriculture and industry, and even international prices, etc. In reality, however, these prices remain subject to political compulsions, quite often divorced from the situation of 'free markets'. Thus, the restrictive trade and pricing policies with respect to rice and wheat have `distorted' the incentives for cultivators of these crops vis-à-vis what they would have been under an open economy environment.

On the other hand, production of rice and wheat have been accorded priority in terms of research funds and subsidies flowing through input prices such as canal waters, power, fertilizers, and credit. It is well-known that input subsidies have largely gone to irrigated crops such as sugarcane, wheat and rice. Over years, the burden of input subsidies has increased manifolds making it almost financially unsustainable. The charges for canal waters do not cover even 10% of the working expenses. In some states (like Bihar), the cost of collection is more than the revenue collected. This has started affecting adversely the quality of maintenance and thereby quality of irrigation service. In case of power, almost all the State Electricity Boards are in the red because of power tariffs for agriculture. There are states (like Punjab) that give free power to farmers. The subsidy on fertilizers is no less. It is set to cross Rs 100 billion mark in 1998-99. The rural credit system is in shambles due to high default rates and lower interest rates in agriculture. All these subsidies together account for 8% of agricultural GDP, and a larger part of this goes to wheat and rice. The ballooning bill of subsidies leads to resource crunch in central and state budgets, and thereby affects investments adversely (Gulati and Sharma 1997).

What would happen to wheat-rice cultivation in the Indo-Gangetic plains in a world where controls on trade, both domestic and external, are abolished and input subsidies reduced/rationalised? It may be worth noting that as per the new trading rules, India will have to soon lift all quantitative restrictions on imports and exports. The highest tariff binding that India has already committed to WTO for rice is zero. For wheat, although the maximum tariff binding is 100%, it is not likely to be exercised by India because of her own economic reform program, which suggests zero import duty for essential commodities (see GOI 1991, Chelliah Committee). Economic reforms program launched since July 1991 also seeks to reduce and rationalise input subsidies. Although politically, it is becoming increasingly difficult to navigate reforms on subsidy front, yet the rising deficits in the budgets are compelling the policy makers, time and again, to find out ways to tackle this difficult area. It is being increasingly felt that open-ended subsidies cannot continue for long, and budgetary compulsions would soon become too acute to "take the bull by the horn".

This paper, therefore, has cut out some specific tasks. First, it attempts to measure the impact of trade and pricing policies including those of input subsidies, on the "effective incentives" for the cultivators of wheat and rice. This is with a view to examine what would happen to these incentives when the trade policy becomes liberal and input subsidy policy is rationalised. Second, it examines the issue of "economic efficiency" in the use of resources in wheat and rice cultivation against the backdrop of an open economy environment. This is done by estimating the "true resource cost" of producing rice and wheat, as against their financial costs, in the states of Indo-Gangetic belt. That means one will have to adjust for several subsidies that are being doled out to farmers for producing wheat and rice in this region. Third, we look at some other countries in the world who are major producers/exporters/consumers of wheat and rice and examine their "producers subsidy equivalents" (PSEs). The idea is to know what would happen to wheat and rice in the Indo-Gangetic plains if subsidies on these crops are withdrawn and globalization (free trade) takes place in its true sense. Would wheat and rice cultivation be cut back in this belt or will it prosper even more? We may also touch upon the issue of groundwater table, especially in Punjab, which is intertwined with wheat-paddy domination in the cropping systems.

Effective Incentives and Efficiency in Wheat-Rice Cultivation

Methodological framework

How does one measure "effective incentives" to cultivators and "economic efficiency" in the production of a commodity under an open economy environment? The standard literature on the subject talks of two basic indicators: effective rates of protections (ERPs) to measure "effective incentives" and domestic resource cost (DRC) to measure "economic efficiency". Distortions in the cultivation of wheat and rice in other countries are measured through producer subsidy equivalents (PSEs). ERPs have different variants such as nominal protection coefficient (NPC), effective protection coefficient (EPC) and effective subsidy coefficient (ESC). Each variant has increasing level of sophistication and superiority to take care of complex issues ranging from prices of outputs to prices of tradable inputs and subsidies on non-tradable inputs (Scandizzo and Bruce 1980, Gulati with Hanson and Pursell 1990, Gulati and Kelley 1999). These measures of effective incentives still do not 'shadow price' the primary factors of production, namely, land and labor. This is taken care of in the concept of DRC, which covers all factors of production and other input costs, values them at their "real economic prices" to find out the "true resource cost" of producing any commodity. The PSEs measure the value of monetary transfers to agriculture resulting from agricultural policies in any given year. These transfers may take place through consumers or through general tax payers (through budgets). PSE can be expressed in absolute value terms, as a ratio to production or as a ratio to value of production to producers (see Annexure I for details).

Estimates and interpretation of effective incentives and economic efficiency

Table 1 presents the estimates of protection coefficients and resource cost ratios for wheat and rice in the selected states of Punjab, Haryana and Uttar Pradesh for the period 1983–93. We feel that this period is long enough to capture the changes in technology as well as wide variations in world and domestic prices. The estimates reveal that the level of effective incentives for the cultivators of wheat and rice has been below unity under the importable hypothesis, on an average, for the entire period covered in the study. This indicates that against the backdrop of an open economy, cultivators of wheat and rice in India have been 'disprotected' or implicitly 'taxed' through trade and pricing policies, if India is considered as a net importer of grains. And this is true because India has been a net importer of grains during this period. This result of implicit 'taxation' holds true even after accounting for the input subsidies, as is revealed by the level of ESCs (Fig. 1).

But if one were to look into the future, presuming that India can be a net exporter of grains, it would be exportable hypothesis that would be more relevant for the policy maker. Here it is important to mention that there are some studies such as Bhalla and Hazell (1997) which paint India as a major importer of grains by 2020. However, we still feel that India is likely to be a net exporter though very marginal (Gulati and Dev 1996). Keeping this in view, we have also estimated incentive indicators under exportable scenario. One finds that the estimates of effective incentives for wheat cultivators approach towards unity as one moves from importable to exportable hypothesis (Fig. 1). The estimates of rice, however, still remain below unity. This indicates whereas rice cultivators have been "disprotected" both under importable and exportable scenarios, wheat cultivators have been "disprotected" largely under importable scenario.

In terms of policy implications, what these estimates indicate is that even if one were to abolish input subsidies and let the output prices be determined by free play of markets (without any distortions in internal or external trade), the cultivators of rice and wheat would be the net gainers. This is under the scenario that India is a net importer of grains. But if India emerges as a consistent exporter of grains, and prices hover near export parity levels, rice cultivators would still gain while wheat cultivators may not really gain much during all years. Sometimes, they may be able to export and get the benefit, especially when domestic price is below the export parity level. But in other years, they may contribute only to building up of stocks which cannot be exported, as the domestic price may be in between the export and import parity band.

With regard to the issue of economic efficiency, the estimates of RCRs of both wheat

Table 1. Incentive and efficiency indicators for rice and wheat (Shadow Exchange Rate).

Crop/incentive and efficiency indicators	States	TE 1983/84	TE 1986/87	TE 1989/90	TE 1992/93	Average
Importable Scenario						
Rice						
NPC	Haryana	0.64	0.84	0.57	0.52	0.64
	Punjab	0.64	0.84	0.57	0.52	0.64
	Uttar Pradesh	0.57	0.73	0.51	0.47	0.57
EPC	Haryana	0.58	0.81	0.53	0.49	0.60
	Punjab	0.60	0.81	0.53	0.48	0.61
	Uttar Pradesh	0.54	0.71	0.47	0.45	0.54
ESC	Haryana	0.63	0.90	0.61	0.55	0.67
	Punjab	0.63	0.87	0.59	0.52	0.65
	Uttar Pradesh	0.60	0.81	0.56	0.51	0.62
RCR	Haryana	–	0.77	0.78	0.85	0.80
	Punjab	0.57	0.68	0.55	0.52	0.58
	Uttar Pradesh	0.49	–	0.53	–	0.51
Wheat						
NPC	Haryana	0.69	0.73	0.65	0.55	0.66
	Punjab	0.69	0.74	0.66	0.56	0.66
	Uttar Pradesh	0.64	0.67	0.60	0.52	0.61
EPC	Haryana	0.61	0.64	0.58	0.48	0.58
	Punjab	0.60	0.66	0.58	0.49	0.58
	Uttar Pradesh	0.56	0.60	0.51	0.47	0.54
ESC	Haryana	0.64	0.69	0.63	0.52	0.62
	Punjab	0.63	0.69	0.62	0.52	0.62
	Uttar Pradesh	0.59	0.64	0.56	0.50	0.57
RCR	Haryana	0.60	0.63	0.48	0.45	0.54
	Punjab	0.62	0.63	0.50	0.51	0.57
	Uttar Pradesh	0.54	0.50	0.39	0.40	0.46

Continued

Table 1. Concluded.						
Crop/incentive and efficiency indicators	States	TE 1983/84	TE 1986/87	TE 1989/90	TE 1992/93	Average
Exportable Scenario						
Rice						
NPC	Haryana	0.74	1.03	0.68	0.63	0.77
	Punjab	0.74	1.03	0.69	0.63	0.77
EPC	Haryana	0.69	1.04	0.65	0.60	0.75
	Punjab	0.71	1.04	0.65	0.59	0.75
ESC	Haryana	0.75	1.15	0.75	0.68	0.83
	Punjab	0.97	1.49	0.92	0.82	1.05
RCR	Haryana	–	0.99	0.96	1.05	1.00
	Punjab	0.68	0.87	0.68	0.65	0.72
Wheat						
NPC	Haryana	0.94	1.06	1.03	0.88	0.98
	Punjab	0.95	1.07	1.04	0.89	0.99
EPC	Haryana	0.95	1.12	1.13	0.91	1.03
	Punjab	0.94	1.14	1.15	0.93	1.04
ESC	Haryana	1.01	1.21	1.24	0.98	1.11
	Punjab	0.99	1.20	1.23	0.98	1.10
RCR	Haryana	0.91	1.13	0.82	1.01	0.97
	Punjab	0.95	1.11	0.86	0.91	0.96

Notes:
TE = Triennium ending.
NPC = Nominal protection coefficient. EPC = Effective protection coefficient.
ESC = Effective subsidy coefficient. RCR = Resource cost ratio.

and rice remain below unity under importable as well as exportable hypotheses. This indicates that the use of resources in the production of wheat and rice is economically efficient both from the point of view of import substitution and export promotion. Within the three states, there is a difference in the estimates of RCR of rice with Uttar Pradesh and Punjab showing

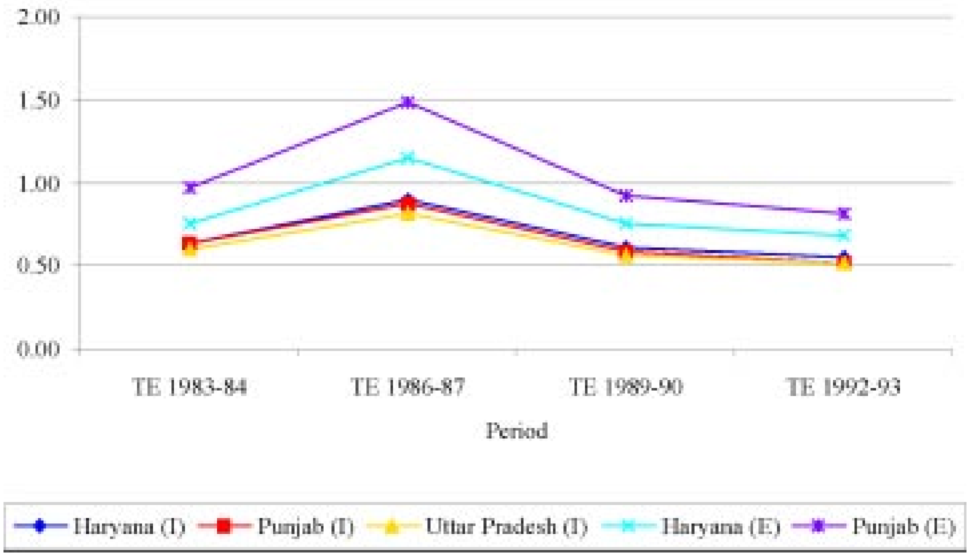


Figure 1a. Temporal behavior of ESCs of rice.

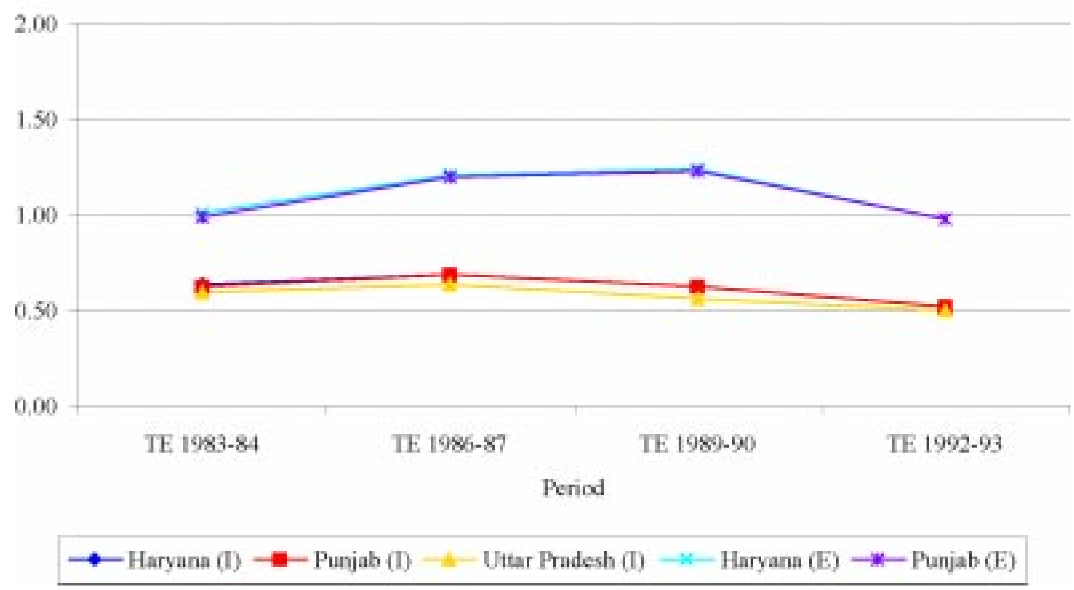


Figure 1b. Temporal behavior of ESCs of wheat.

higher levels of economic efficiency (lower RCR) in rice production than Haryana. And in case of wheat production, resource use efficiency is higher in Uttar Pradesh than in Punjab and Haryana. The policy implications of these results are clear: to promote economic efficiency in the use of resources, from society's point of view, it would be better to encourage production of wheat and rice in all the three states, though at the margin Uttar Pradesh will score over Punjab and Haryana.

Estimates and interpretation of PSEs in selected countries

Table 2 provides PSEs of rice and wheat in selected countries over the period 1982–92, also

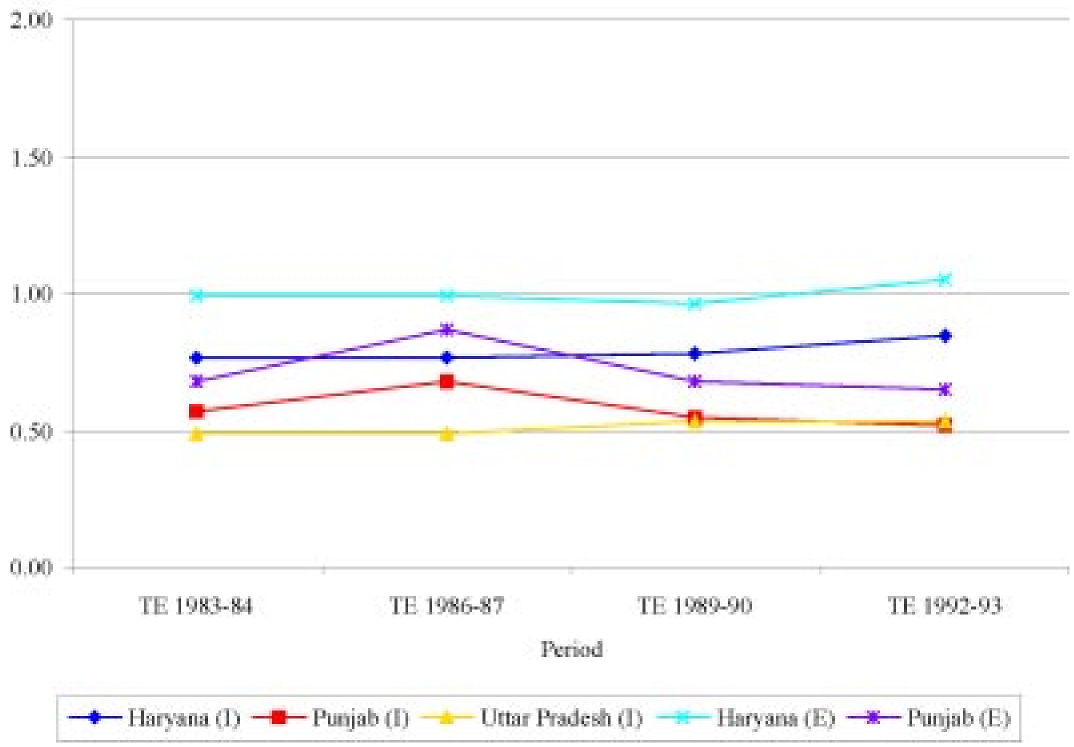


Figure 1c. Temporal behavior of RCRs of rice.

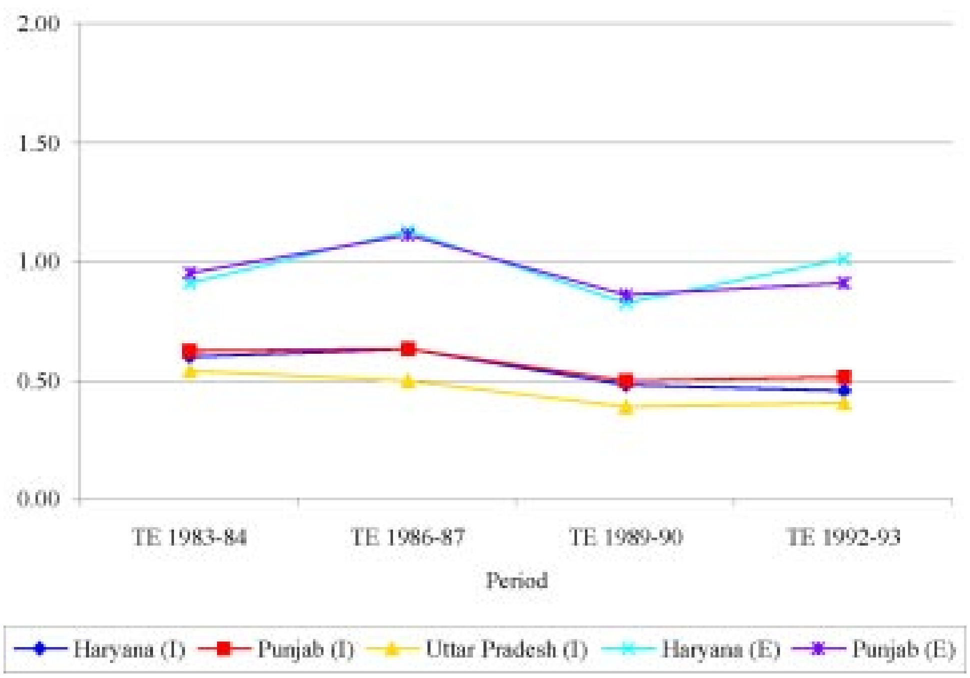


Figure 1d. Temporal behavior of RCRs of wheat.

clubbed as average of 1982–87 and 1988–92, a period almost similar to that covered in our indicators of effective incentives and efficiency in the Indo-Gangetic plains. If one looks at the average of 1988–92 results, it is interesting to see that in case of rice, the range of PSEs stretches from –65% in case of Egypt to +92% in case of Japan. In case of wheat, the range is even wider, from –109% in case of Zambia to +102% in case of Japan. However, the support to wheat farmers in major producing and exporting countries is somewhat less: US 39%, EC 20% for soft wheat and 42% for durum wheat, Canada 38%. It is only countries in the

Table 2(a). Countrywise state support to wheat.

Country	Avg-1982–92	Avg-1982–87	Avg-1988–92
USSR	–23.64	15.95	–50.03
Argentina	–20.30	–17.30	–22.71
China	–4.67	3.75	–11.40
India	–11.01	–4.85	–23.33
Egypt	26.25	26.67	26.00
Nigeria	15.01	–2.45	67.40
Turkey	23.56	12.93	32.06
Australia	3.88	4.14	2.58
South Africa	–1.34	6.30	–24.25
Chile	0.70	13.30	2.14
Mexico	43.71	46.84	41.20
EC-soft	28.36	31.00	20.45
EC-durum	41.00	40.52	42.45
Canada	40.56	43.83	37.94
United States	42.51	47.28	38.70
Yugoslavia	20.74	34.12	12.10
Poland	47.29	63.36	7.10
Brazil	51.18	51.18	–
Taiwan	75.56	70.00	80.00
Japan	99.96	98.75	102.37
Columbia	31.58	35.93	28.11
Czechoslovakia	–45.74	–56.62	–18.55
Kenya	24.04	20.98	33.20
Tanzania	–51.58	–39.17	–88.80
Zambia	–38.24	18.24	–108.85
Zimbabwe	–8.00	–11.33	2.00

Source: USDA (1994).

Cairns group like Australia that had support to wheat cultivators to the tune of just 2.6%. India had a negative support (implicit taxation) to wheat cultivators to the tune of 23% of the value of wheat production during 1988-92, a result quite consistent with our findings of effective incentives and efficiency indicators in the Indo-Gangetic plains. In case of rice, India had an even bigger negative support (implicit taxation) to the tune of -44% during 1988-92, which is also consistent with our findings for the rice cultivators in the Indo-Gangetic plains. China, another major producer of rice, also taxes its farmers, the PSE being –26%, though not as much as India does. There are issues like how far world reference price can be taken as given for big countries like China and India, especially in case of rice where the world market is pretty small compared to their domestic production. If these two countries enter in any big way, either as exporters or importers, the world reference price for rice may undergo a change, and so also the calculation of PSE. Although the point is well taken and some refinement needs to be done to PSEs or even indicators of effective incentives relaxing the 'small country' assumption,[1] yet the existing set of PSEs do give an indication of what would happen to world production of wheat and rice, if (and that is a big IF!) true globalization takes place. If one arranges these selected countries in an ascending order of their PSEs on the y-axis and cumulative production of rice (or wheat) on the x-axis, what one would obtain is a resource cost curve of rice (and wheat) production in the world (Gulati and Narayanan 1999). These curves are akin to commodity-specific marginal cost curves (Fig. 2). With gradual reduction in government support to agriculture, as indicated in the URA, the production of rice and wheat

Table 2(b). Countrywise state support to rice.

Country	Avg-1982-92	Avg-1982-87	Avg-1988-92
China	–13.11	2.75	–25.80
Egypt	–55.75	–40.33	–65.00
Kenya	0.61	9.47	–25.95
India	–15.14	–0.65	–44.13
Australia	14.86	13.72	12.58
Taiwan	45.56	34.25	54.60
Nigeria	69.94	88.15	15.30
United States	47.43	51.20	44.42
European Communtiy	50.35	48.18	56.85
Brazil	58.50	58.50	–
South Korea	77.91	70.74	86.88
USSR	70.00	92.90	54.73
Japan	89.46	87.98	92.40
Columbia	24.68	27.90	22.10
Jamaica	13.09	–3.80	63.76
Mexico	35.50	51.87	22.41

Source: USDA (1994).

1. This has been attempted elsewhere (see Gulati and Pursell 1999)

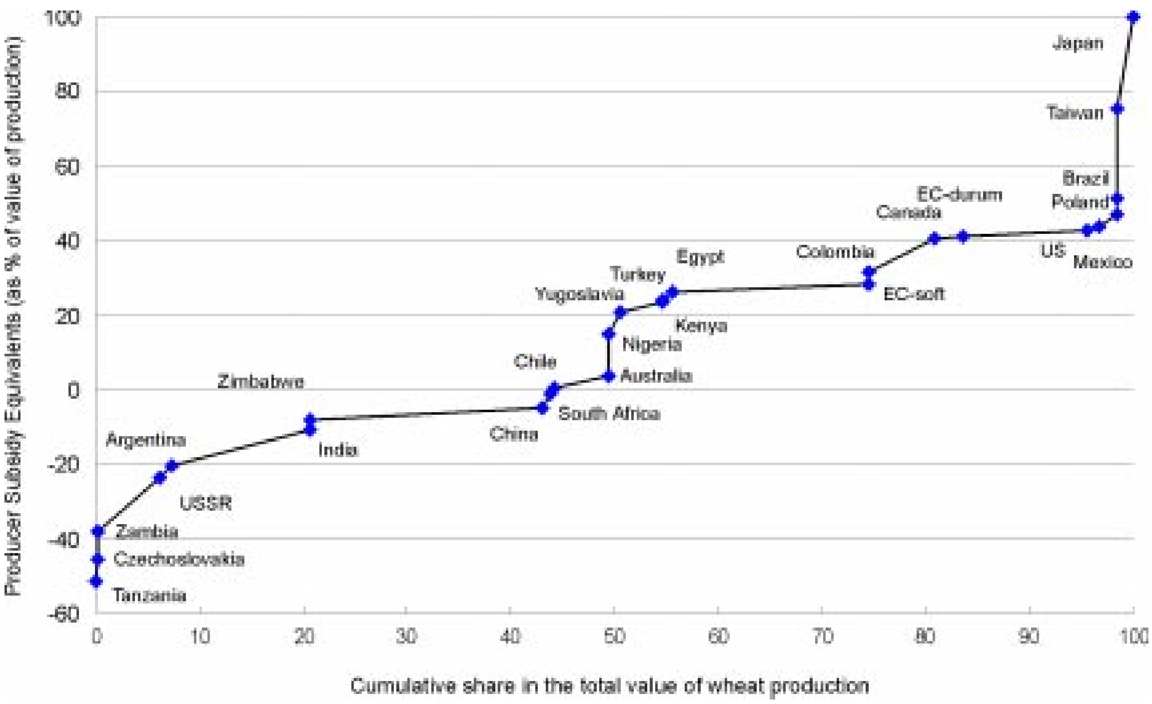
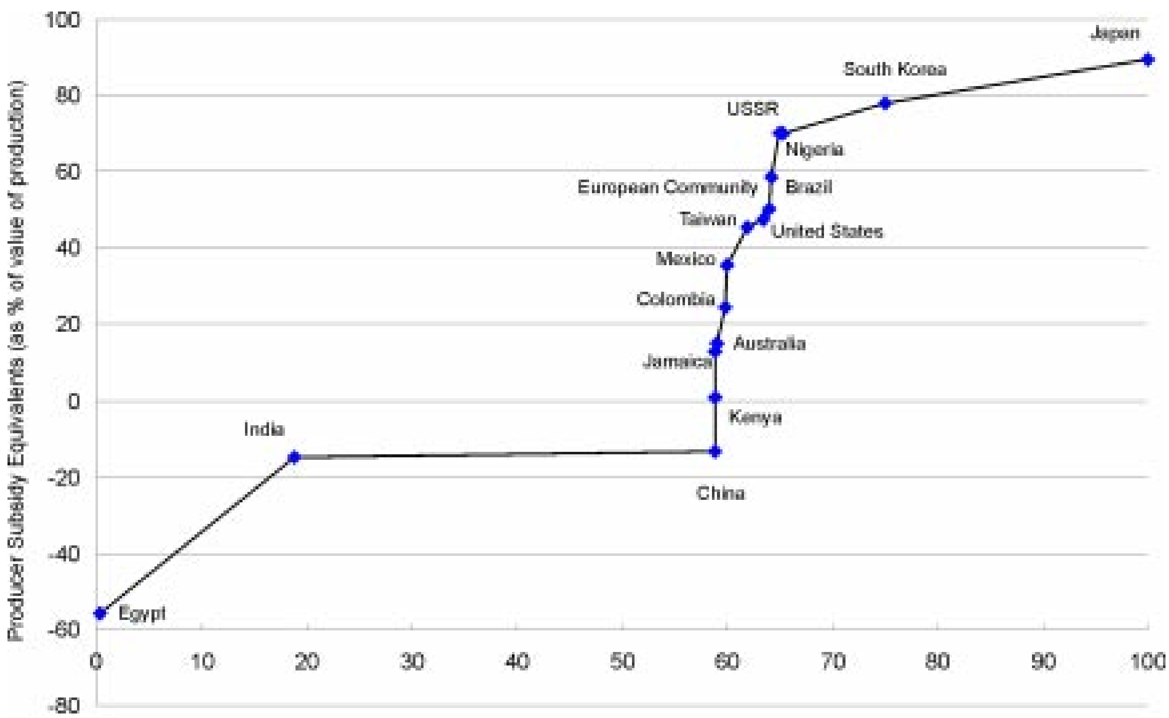


Figure 2a. State support to wheat production across selected countries 1982-92.



Cumulative share in the total value of rice production

Figure 2b. State support to rice production across selected countries 1982-92.

in countries at the higher end of the commodity-specific MC curves will become economically unviable and, therefore, is likely to shrink. On the other hand, their production in countries at the lower end of MC curve will become more profitable with liberalisation and, therefore, should logically expand. This would lead to more efficient use of world resources. India appears towards the lower end in both the curves, and thus one should expect that cultivators of wheat and rice in India including those in the Indo-Gangetic plains are likely to gain in this fast globalizing world.

At this juncture, it may be worth noting that our estimates of economic efficiency, as measured by RCRs or as indicated by PSEs, do not attach any value to declining water table in Punjab due to rice-wheat rotation. What we adjust for is basically the subsidies on canal waters, power, fertilisers and credit. And removal of these subsidies, though politically very difficult, does not make major changes in our calculations of 'economic efficiency'. But the fall in water table is a matter of concern raising doubts regarding sustainability of rice-wheat system. There are varying estimates of the fall in water table. But simulations on the water balance of the state (presuming current cropping patterns to continue over the next 20 years) show that water table is likely to fall by an average of about 15 cm per year (Gulati et al. 1998). How can one control this? The instruments with policy makers are pricing of power, restrictions on credit for more tubewells in that area, and so on. But all these are not likely to be very effective in controlling the receding water table. Our experiments to examine the impact of raising irrigation cost on paddy area reveal that the elasticity of paddy area to any such changes in irrigation cost is very low (0.027, see Gulati et al. 1998). Thus, a realistic way to come out of this problem of falling water table is to provide the rice cultivators alternative crops that consume less water but are more remunerative. At present, the traditional maize crop does not come anywhere near paddy in terms of relative profitability. Sugarcane is, but its consumptive use of water is more than what rice-wheat system takes. The progress towards high value horticultural crops, though encouraging, is not on a very large scale to make any major dent in the rice areas of Punjab. Thus, search for an alternative and more profitable crop than rice, remains a challenge to crop technologists and policy makers concerned with the falling water table in Punjab.

Concluding Observations

We set out to estimate the "incentive and efficiency status" of wheat and rice in the selected states of Punjab, Haryana and Uttar Pradesh, as they evolved since 1980 in response to factors guided by the closed and regulated economic regime. The objective, however, was futuristic, i.e., to examine how this "incentive and efficiency status" would change with India's inevitable transition to an open, liberal economy. Accordingly, we also presented the support levels, measured through PSEs, to wheat and rice cultivators in major countries in the world. It is to be realised that it is not a matter of purely theoretical interest, but of immense practical importance to policy makers given that India, as other signatories to URA, is now committed to open her agriculture as per the trading rules of WTO and has already launched economic reforms at home since 1991.

The estimates of effective incentives and efficiency in resource use presented under the heading "Effective Incentives and Efficiency in Wheat-Rice Cultivation" in the foregoing pages, reveal that the selected states are efficient producers of wheat and rice against the backdrop of global economy. This result is reinforced by looking at PSEs of wheat and rice across several countries. This has occurred despite several controls on the free marketing of these crops in the past. With freeing up of trade, and removing distortions in domestic markets, the effective incentives for cultivators of wheat and rice are likely to increase. This is largely true even when input subsidies are withdrawn/ rationalised. As a result, their production is likely to increase unless there are other competing crops with higher returns, after discounting for risk. From society's point of view too, increased production of wheat and rice in the New Brave World of free trade would raise economic efficiency in the use of resources. It also helps in fulfilling the 'food security' objective. With the opening up of trade and reductions in government support in developed countires, therefore, there is a strong possibility of wheat and rice taking a further fillip in the plains of the Indo-Gangetic belt.

Given this scenario, there is one major concern, and that is of sustaining this rice-wheat system within the existing water resources of the states. The problem is already coming to surface in Punjab, and to some extent in Haryana, and may soon spread to western Uttar Pradesh. The total demand for water that this cropping system requires is more than the current supplies. As a result, the ground water buffer is being used to fill the gap. This is not an encouraging sign. With withdrawals consistently higher than the recharge, it would deplete the water table and affect the long-term sustainability of the system. The pricing instruments to check this type of a trend are not very strong, besides the political overtones they assume. Can the new technologies and/or institutions for distributing water to farmers be of any help to check this problem? Should more investments need to be made to augment canal water supplies to recharge groundwater? It appears that a more realistic way out would be to look for alternative crops with higher returns so that farmers start switching to less water intensive at the margin. And that remains a challenge to crop scientists and economists.

Annexure 1

Methodology for Measuring Effective Incentives and Efficiency

The NPC is measured as the ratio of domestic price to world reference price. The EPC goes a step further by incorporating tradable inputs into the analysis in such a way that it measures the ratio of value added at domestic prices to value added at world reference prices. The ESC adds net subsidies on non-tradable inputs into the numerator of the EPC, while keeping the denominator same. In other words, the value added at domestic prices in EPC is adjusted for the net subsidies on non-tradable inputs to give ESC. Symbolically the three variants can be expressed as follows:

$$NPC_i = P_i^d / P_i^w$$

$$EPC_i = \left[Q_i \left(P_i^d - \sum_{j=1}^{k} A_{ij} P_j^d \right) \right] \Big/ \left[Q_i \left(P_i^w - \sum_{j=1}^{k} A_{ij} P_j^w \right) \right]$$

or

$$EPC_i = V_i^d \; / \; V_i^w$$

$$ESC_i = \left\{ \left[Q_i \left(P_i^d - \sum_{j=1}^{k} A_{ij} P_j^d \right) + \left(\sum_{j=k+1}^{j} A_{ij} S_j - \sum_{j=k+1}^{j} A_{ij} T_j \right) \right] \right\} \Big/ \Big[Q$$

where

NPC_i	Nominal Protection Coefficient of the commodity *i*
P_i^d	Domestic price of commodity *i*
P_i^w	World reference price (border price equivalent) of commodity *i*, adjusted for transportation, handling and marketing expenses
EPC_i	Effective Protection Coefficient of commodity *i*
Q_i	Quantity of output of *i*th commodity
A_{ij}	Quantity of *j*th input required to produce a unit of commodity *i*
P_j^d	Domestic price of *j*th traded input
P_j^w	World Reference Price (border price-equivalent) of *j*th traded input, adjusted for transportation, handling and marketing expenses
V_i^d	Value added at domestic prices
V_i^w	Value added at world reference prices (border price-equivalents)
ESC_i	Effective Subsidy Coefficient of the commodity *i*
S_j	Subsidy on the *j*th non-traded input

T_j Tax on the jth non-traded input

$\left(\sum_{j=k+1}^{j} A_{ij} S_j - \sum_{j=k+1}^{j} A_{ij} T_j \right)$ Subsidies (net of taxes) on non-traded factors of production

Mention must be made here that the appropriate exchange rate used to convert international reference prices into comparable domestic currency equivalents can be official exchange rate, provided there are no serious distortions in the foreign exchange market. But if there are severe controls on imports, and if the exchange rate of the domestic currency is not market determined, as was the case in India prior to 1991, use of official exchange rate can lead to misleading interpretation of results. In such a situation, it is preferable to estimate and use 'free market exchange rate' or 'shadow exchange rate' to convert international prices into domestic currency. The shadow exchange rate is a rate that would have prevailed if exports and imports were open and the current account in Balance of Payments account cleared without any deficit. We have not estimated this rate in this study but relied on the results of another study, which puts the shadow exchange rate at 20 per cent higher than the official exchange rate, on an average basis for the period 1970-90, although there are fluctuations from year to year.

Another point worth noting in this methodological framework is that these indicators of effective incentives can vary significantly depending upon whether they are estimated under 'importable hypothesis' or 'exportable hypothesis'. Under ***importable hypothesis***, it is presumed that the domestic production of that commodity is for import substitution while under ***exportable hypothesis*** the domestic production is basically for exports. The results under the two scenarios differ because of the differential treatment accorded to transportation costs and associated marketing expenses (Gulati and Kelley, 1999).

The DRC, on the other hand, is defined as the value of domestic resources (primary, non-traded factors of production such as land, labour and non-traded capital) needed to earn or save a unit of foreign exchange through the production of the commodity under consideration. The DRC concept also has different variants (Bruno 1976 and 1972, Krueger 1966 and 1972). But here we use the following expression, as given in Scandizzo and Bruce (1980):

$$DRC_i = \left(\sum_{j=k+1}^{J} A_{ij} P_j^s \right) \Big/ \left(P_i^w - \sum_{j=1}^{k} A_{ij} P_j^w \right)$$

where

DRC_i Domestic Resource Cost of saving or earning a unit of foreign exchange through the production of one unit of *i*th commodity;

A_{ij} Quantity of *j*th input required to produce a unit of commodity *i*;

P_j^s Shadow Price (social price or opportunity cost) of *j*th non-traded input;

$\sum_{j=k+1}^{J} A_{ij} P_j^s$ Normative cost of all those *j* inputs (needed to produce one unit of *i*th commodity) that are direct, primary, non-traded plus the indirect, primary, non-traded elements of non-traded items obtained after decomposition. The normative costs are the 'true' costs to the society, after adjusting for subsidies etc., if any;

P_j^s Shadow price of jth non-traded input;

$\sum_{j=1}^{k} A_{ij} P_j^w$ The world value of all those j inputs directly traded plus the indirect traded elements of non-traded items obtained after decomposing the non-traded items into tradable and non-tradable;

$j=1..k$ Directly traded inputs plus the traded elements of non-traded inputs obtained after decomposing the non-traded items into tradable and non-tradable;

$j=k+1..J$ Primary inputs plus non-traded elements of non-traded inputs obtained after decomposing the non-traded items into tradable and non-tradable.

This expression provides the 'true cost' of domestic resources that are needed to earn/save a unit of foreign exchange by production of commodity '*i*'. This is also known as the commodity-specific shadow price (in this case '*i*') of foreign exchange. If this DRC is divided by the economy-wide shadow exchange rate (given exogenously), we get the resource cost ratio (RCR), which is a pure number. If this ratio happens to be greater than unity, it would indicate that the 'true cost' of production of the commodity under consideration is more than the resources required at economy-wide level to earn/save a unit worth of foreign exchange. That would indicate that commodity under consideration is not maximising efficiency in resource use and, therefore, at the margin, its production needs to be curtailed. The opposite would be true if the RCR happens to be below unity. A ranking of RCRs for different crops across various regions helps to estimate the degree of comparative advantage/disadvantage in producing some crops in certain regions as opposed to others.

Before we discuss the results of this exercise, certain qualifications in respect of shadow prices of primary non-tradable factors of production may be noted. There is ample discussion in the literature to estimate shadow prices of primary factors (UNIDO 1972 and 1978, Little and Mirrlees 1974, Tower and Pursell 1976, Squire and Tak 1988). The *shadow price* of a resource is defined as the value of benefits foregone by society by employing that resource in the production of a particular commodity. The shadow prices are difficult to estimate empirically because there are numerous activities in which resources can be used. As a result, several approximations have to be used to estimate social prices, particularly of non-tradable inputs. The resulting estimates, therefore, remain specific to the underlying assumptions used in any such study. The procedure and the assumptions used in this study for estimating shadow prices are the same as used in Gulati and Kelley (1999).

Producer Subsidy Equivalents (PSEs) are aggregate measures of support –they summarise the effects of different forms of governmental programs and intervention in a single number. This method is superior to other tools like nominal or effective rates of protection since these often account for only a small proportion of the transfers between the government and the producers of agricultural commodities.

The PSE is essentially a comparison of two states: the current, where there is government intervention and a hypothetical one, where such intervention is absent. Government intervention is a list of policies that affect production; farmers' production decisions under current policies are applied to both states. The subsidy for each policy is calculated piece-wise with the other policies held in their current state. The subsidy is summed over the different policy instruments for each commodity to give commodity PSEs. Aggregate PSEs are in turn obtained by adding across all the commodities. The most common interpretation of the PSE is that it represents the amount of compensation that would be required to maintain farm incomes if government intervention (in the form of policies that affect agricultural markets) were eliminated, assuming constant world prices and fixed output.

PSEs can be represented in many forms depending on the sort of comparison one desires to make. Two in particular are appropriate and suitable for cross-country comparisons. The first measure divides the PSE by the value to the producers and is multiplied by 100 to get the percentage PSEs. It presents the PSEs relative to the size of the farmers' gross revenue. The other is PSE per unit of output of a commodity where the PSE is divided by the level of production. This measure reflects the subsidies provided by the government for the production of a unit of output. For the purpose of this paper, percentage PSEs are considered rather than PSE per unit of output.

Symbolically, PSE can be defined as:

$$\%\text{age PSE} = \text{Total Transfers/ Value to Producers}$$

$$= \{Q * (P_d - P_w * X) + D + I\} / (Q * P_d + D)$$

Q is the quantity produced,
P_d is the producer price in domestic currency units,
P_w is the world price in world currency units,
X is an exchange conversion factor,
D is direct government payments, and
I is indirect transfers through policies such as input subsidies, marketing assistance and exchange rate distortions.

The value of %age PSE could be negative or positive depending upon whether the domestic price is less than or greater than the world reference price and whether other payments by the government are able to compensate the farmers for the 'implicit tax' in case domestic price is lower than the reference price. So, this concept is somewhat akin to ESC below unity or above unity.

In interpreting the PSEs and analyzing the trends in the same a few points are to be noted. Firstly, it is important to note that changes in world prices, exchange rates or domestic production can alter the PSE even if the government policies were to remain the same. In particular, exchange rate fluctuations are rather pronounced for some countries and to interpret PSE changes disregarding exchange rate fluctuations would be erroneous. Moreover, all transfers do not have the same weight in the percentage PSE calculation. Transfers from price support programs (the effects of which are included in P_d) as well as direct payments (D) appear in both the numerator and the denominator. Indirect transfers (I) on the other hand appear only in the numerator. This implies that a country can lower the PSE without changing total transfers to producers merely by shifting transfers from indirect programs to price support programs or direct payments.

References

Bhalla, G.S. and **Hazell, P.B.R.** 1997. Foodgrains demand in India to 2020: a preliminary exercise. Economic and Political Weekly, December 27, 1997.

Bruno, Michael 1967. Development policy and dynamic comparative advantage, *in:* The technology factor in international trade (Vernon, R., ed.). New York.

Bruno, Michael 1972. Domestic resource costs and effective protection: clarification and synthesis. J. Political Economy, Vol. LXXX, No.1.

Government of India 1991. Interim report of the tax reform committee (Chairman Raja Chellia), GOI, New Delhi.

Gulati, Ashok with **Hanson, James** and **Pursell, Garry** 1990. Effective incentives in India's agriculture. Policy Planning and Research Working Paper No. 332 (Trade Policy), World Bank.

Gulati, Ashok and **Sharma, Anil** 1997. Subsidies and investments in Indian agriculture. *in:* Subsidies and investments in Indian agriculture, conference papers, Rajiv Gandhi Institute for Contemporary Studies (RGICS), Project No. 21.

Gulati, Ashok and **Dev, Mahendra** 1996. India's integration into the global economy: medium and long-term implications for Indian agriculture and linkages to OECD countries. Paper written for OECD, Paris.

Gulati, Ashok and **Kelley, Tim** 1999. Trade liberalization and Indian agriculture. New Delhi, Oxford University Press.

Gulati, Ashok and **Pursell, Garry** 1999. Trade policies, incentives and resource allocation in Indian agriculture. Mimeo.

Gulati, Ashok, Chopra, Kanchan and **Saxena, Padamja** 1998. Reforming the regime of subsidies: implications for the agricultural sector (irrigation and power). Mimeo, Final Report of a project sponsored by the Government of India, IEG.

Krueger, Anne O. 1966. Some economic costs of exchange control: the Turkish case. J. Political Economy, Vol. LXXIV, No. 5.

Krueger, Anne O. 1972. Evaluating restrictionist trade regimes: theory and measurement. J. Political Economy, Vol. LXXX, No. 1.

Little, I.M.D. and **Mirrlees, J.A.** 1974. Project appraisal and planning for development countries. London, Heinermann.

Murty, M.N., Goldar, B.N., Kadekodi, Gopal, and **Mishra, S.N.** 1993. National parameters for investment project appraisal in India. Institute of Economic Growth, Working Paper No. E/153/92.

Scandizzo, P.L. and **Bruce, Colin** 1980. Methodologies for measuring agricultural price intervention effects. World Bank Staff Working Paper No. 394. World Bank.

Squire, L. and **Van der Tak, H.G.** 1988. Economic analysis of projects. Baltimore, Md., USA. Johns Hopkins University Press.

Tower, Edward and **Pursell, Garry** 1976. On shadow pricing foreign exchange, goods and factors. Typescript, World Bank.

UNIDO 1972. Guidelines for project evaluation. Project Formulation and Evaluation Series No. 2, Vienna.

UNIDO 1978. Guide to practical project appraisal - social benefit cost analysis in developing countries. Project Formulation and Evaluation Series No. 2, New York.

Sustainability of Rice-Wheat Based Cropping Systems in India: Socio-economic and Policy Issues

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Abstract

During the last three decades, the rice-wheat based cropping systems(RWCS) in India have significantly contributed in enhancing the food grain production and achieving the food self-sufficiency and food security. The production system now is under threat due to stagnating or declining crop productivity, and threatening the issues related to sustainability. This paper attempts to measure sustainability of the RWCS using total factor productivity (TFP) approach. It also examines the role of legumes, if any, in improving the sustainability of this most important and productive system in the country. The results suggest that the growth in TFP of dominant RWCS has either declined or stagnated. Legumes play important role in improving the sustainability of the system. Ironically, rice and wheat have replaced the principal legumes over a period of time. With the availability of high-yielding and short-duration varieties of important legumes, there is a need to incorporate them in the RWCS to improve the sustainability of the system so as to meet the future food grain demands without degradation of the natural resource base.

Introduction

Rice-wheat cropping systems (RWCS) gained prominence with the introduction of short-duration and high-yielding varieties of rice and wheat during mid-1960s. The rotation has spread in the most fertile regions and has covered about 10 million ha. in the Indo-Gangetic plains (IGP) of India. It is more popular in the non-traditional rice-growing states of Punjab, Haryana and Uttar Pradesh, and less in traditional rice-growing states of Bihar and West Bengal. The impressive performance of the system during the last three decades resulted in a quantum jump in the production of rice and wheat, which largely contributed in achieving the food self-sufficiency in India. The food grain production increased from about 90 million tonnes in 1964-65 to about 190 million tonnes in 1994-95, at an annual growth of little over 2.5%.

While the rapid growth in rice and wheat production yielded high dividends, it was realised during late 1980s that gains may not be sustainable. Currently, there is a growing concern about the sustainability of RWCS as the growth rates of rice and wheat yields are either stagnating or declining (Abrol 1996, Paroda 1996, Ramesh Chand and Haque 1998). The productivity of rice and wheat in some parts has already ceased to increase and in few it has shown declining trends. Chaudhary and Harrington (1993) have shown that the expansion in rice and wheat area in Haryana has halted, growth in rice productivity has

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Kumar, Praduman, Joshi, P.K., Johansen, C., and **Asokan, M.** 1999. Sustainability of rice-wheat based cropping systems in India: socio-economic and policy issues. Pages 61–77 *in* Sustaining rice-wheat production systems: socio-economic and policy issues (Pingali, Prabhu L., ed.). Rice-Wheat Consortium Paper Series 5. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

slowed down, and historical sources of productivity growth have exhausted much of their potential. Cultivation of rice and wheat have become less profitable over time. The threat is further aggravated when the country has to meet the growing food grain requirement, in the absence of any technological breakthrough, of 294 million tonnes by 2020 with a break-up of about 122 million tonnes for rice, 103 million tonnes for wheat, 41 million tonnes for coarse grains and 28 million tonnes for pulses (Kumar 1998). More than three-fourths of the total food grain requirement will be for rice and wheat.

The main questions, therefore, now being raised by scientists and policy makers in this regard are: (i) To what extent the sustainability of the RWCS has been threatened? (ii) How can legumes and organic manures sustain the productivity of the system, and (iii) How can the damage, if indeed, has already occured, be minimized and reversed? The present paper examines these issues to better characterize the performance of the production system. More specifically, the objectives of the paper are to: (i) Assess the significance of RWCS in improving the food security of India, (ii) Diagnose changing use of traditional and modern inputs in the RWCS, (iii) Measure the sustainability of the production system using the TFP approach, and (iv) Examine the role of legumes in improving the sustainability of the RWCS.

Methodology

The study area

The study is confined to the IGP of India. The entire region can be divided into two cropping systems: (i) Rice-wheat based cropping systems (RWCS), and (ii) Rice based cropping systems (RBCS). The former is largely confined in Punjab, Haryana and Uttar Pradesh, and to some extent in Bihar and West Bengal where rice and wheat are grown in a sequence. The second system is practiced more in large parts of Bihar and West Bengal, and to a lesser extent in Uttar Pradesh where land is either kept fallow or allocated to rice after rainy season.

The data

Data on area, production, yield, irrigated area, adoption of high-yielding varieties, farm harvest prices of rice, wheat, and important legumes were collected from published sources from 1970 to 1995(Government of India 1995). This data-set was complemented by the farm-level data on yield, use of inputs and their prices, which were collected from the "Comprehensive Scheme for the Study of Cost of Cultivation of Principal Crops," Directorate of Economics and Statistics, Government of India. Both secondary and the farm-level data-sets were integrated to measure the TFP.

Quantifying sustainability of RWCS

Total factor productivity (TFP) is one measure of quantifying sustainability of any system. Lynam and Herdt (1988) argued that the appropriate measure of output by which to determine sustainability measure at the crop, cropping- or farming- system level is TFP. It is defined as the total value of all output produced by the system over one cycle divided by the total inputs used by the system over one cycle of the system. A sustainable system should have a non-negative trend in TFP over the period concerned. Later, Ehui and Spencer (1990) and Whitaker and Lalitha (1993) used inter-temporal factor productivity to measure the sustainability of a crop or farming system. In this paper, Divisia-Tornqvist index (Diewert 1976) was used to measure TFP as an indicator of sustainability. During the last two decades or so, several studies on TFP have been published for India using similar approach of constructing Divisia-Tornqvist index (Rosegrant and Evenson 1992, Sidhu and Byerlee 1992, Kumar and Mruthyunjaya 1992, Kumar and Rosegrant 1994, Jha and Kumar 1996).

The estimation procedure of TFP is given as follows:

Total output index (TOI)

$$TOI_t / TOI_{t-1} = \prod_j \left(Q_{jt} / Q_{jt-1}\right)^{(R_{jt} + R_{jt-1})^{1/2}}$$

Total input index (TII)

$$TII_t / TII_{t-1} = \prod_i \left(X_{it} / X_{it-1}\right)^{(S_{it} + S_{it-1})^{1/2}}$$

Total factor productivity index (TFP)

$$TFP_t = (TOI_t / TII_t)$$

Input price index (IPI)

$$IPI_t / IPI_{t-1} = \prod_i \left(P_{it} / P_{it-1}\right)^{(S_{it} + S_{it-1})^{1/2}}$$

where R_{jt} is the share of output j in total revenue, Q_{jt} is output j, S_{it} is the share of input i in total input cost, X_{it} is input i and P_{it} is price of input i, all in period t. By specifying TOI_{t-1}, TII_{t-1} and IPI_{t-1} equal to 100 in the base year (1981–82). Grain and straw are included in the output.

The above equations provide the indices of total output, total input, TFP and inputs price indices for the specified period 't'. The real cost of production of crops is computed by deflating the cost of production by input price index.

Significance of the RWCS

Extent of the RWCS

Precise information on extent of RWCS is not available. Some estimates are made by subtracting the area under other possible crop sequences. The estimates reveal that area under RWCS was spread in about 10 million ha in the IGP of India in 1993 (Table 1). During the last three decades, area under this system has risen by more than 6 million ha. About 75% of the

Table 1. Estimated area under rice-wheat based cropping system in the Indo-Gangetic plains, India.

States	Area(mha) of rice-wheat system		Rice-wheat rotation area as % of total rice area		Rice-wheat rotation area as % of total wheat area	
	1983	1993	1983	1993	1983	1993
Punjab	1.35	2.02	100	100	44	63
Haryana	0.51	0.67	100	100	30	36
Uttar Pradesh	5.14	5.25	94	96	61	61
Bihar	1.70	1.90	37	40	96	96
West Bengal	0.11	0.26	2	4	41	98
Indo-Gangetic plains	8.82	9.96	72	75	58	63
India	11.46	12.33	29	30	49	52

Note: Average of triennium ending 1983 and 1993. mha = million hectares

Source: Derived from Government of India (1995).

total rice area and 63% of the wheat area in the IGP was under RWCS in 1993.

State-level disaggregation showed that entire rice area in Punjab and Haryana, and 96% in Uttar Pradesh was under RWCS. In Bihar, the corresponding figure was 40%. Negligible rice area in West Bengal was under this cropping system. On the other hand, almost all the wheat area (which is too low in comparison to rice) in Bihar and West Bengal was in rotation with rice. The corresponding wheat area in the RWCS in Punjab and Uttar Pradesh was little over 60%. It was 36% in Haryana. This suggests that about 40% of the wheat area in Punjab and Uttar Pradesh, and about 64% in Haryana was rotated with crops other than rice.

Contribution of the RWCS in cereals production

The RWCS has substantially contributed to the food grain basket of the country, which made India a self-sufficient nation. The RWCS was contributing more than a half of the cereals production in the IGP (Table 2). About three-fourths of Punjab's cereal production was coming from the RWCS. More than half of the cereal production in Uttar Pradesh and Bihar was contributed by the RWCS. About 46% of the cereal production in Haryana was contributed by the RWCS. In West Bengal, it was less than 10%. At aggregate level, the RWCS contributed a little over 50% in total cereals production in the IGP, and about one-third in India. Thus, the sustainability of the RWCS in the IGP is of great significance to meet the country's growing demand for food grains.

Rice and wheat procurement

The significance of the RWCS can be seen by the procurement of rice and wheat from the region (Table 3). The available information shows that in 1994-95 about 76% of the total food grains in the country was procured from the IGP. About 95% of the wheat and 60% of the rice procurement came from the IGP. Punjab alone contributed about 60% of wheat and 42% of rice in the total food grain procurement in the country. These evidences confirm that the RWCS is the backbone of the public distribution system and food security in

Table 2. Contribution of rice-wheat based cropping system (RWCS) in total cereal production in the Indo-Gangetic plains, India.

States	Production From RWCS(mt)		Total cereal production (mt)		Contribution of RWCS in total cereal production (%)	
	1983	1993	1983	1993	1983	1993
Punjab	8.2	14.1	13.9	19.7	59.0	74.6
Haryana	2.6	4.3	6.2	9.4	41.9	45.7
Uttar Pradesh	14.8	20.5	24.0	33.2	61.7	61.7
Bihar	3.9	5.5	7.7	8.9	58.6	61.8
West Bengal	0.9	1.1	6.9	12.4	13.0	8.9
Indo-Gangetic plains	29.9	44.7	58.7	83.6	50.9	53.5
India	35.6	50.4	125.6	160.7	28.3	31.4

Source: Derived from Government of India (1995). mt = million tonnes.

Table 3. **Procurement of food grains by Government agencies from the Indo-Gangetic plains, India (lakh tonnes).**

State	1981/82	1985/86	1992/93	1994/95	% to total 1994/95
Rice					
Punjab	31.1	42.2	49.1	58.3	42.6
Haryana	8.8	10.4	9.1	14.2	10.4
Uttar Pradesh	7.3	10.7	11.9	7.3	5.3
Bihar	*	*	*	*	*
West Bengal	0.5	0.7	1.7	1.9	1.4
Indo-Gangetic plains	47.7	63.3	71.8	81.7	59.6
India	73.3	98.8	130.3	137.0	100.0
% share of Indo-Gangetic plains to total India	65.1	64.1	55.1	59.6	
Wheat					
Punjab	48.3	64.8	44.9	73.0	59.2
Haryana	12.6	23.4	13.7	31.0	25.1
Uttar Pradesh	13.8	16.0	5.0	13.0	10.5
Indo-Gangetic plains	74.7	104.2	63.6	117.0	94.9
India	77.2	105.4	63.8	123.3	100.0
% share of Indo-Gangetic plains to total India	96.8	98.9	99.7	94.9	
Total Food Grains					
Indo-Gangetic plains	122.4	167.5	135.4	198.7	76.3
India	150.5	204.2	194.1	260.3	100.0
% share of Indo-Gangetic plains to total India	81.3	82.0	69.8	76.3	

* Negligible.

Source: Government of India (1996).

the country. Any threat to this system may seriously affect the food security of the poor living outside the IGP.

Declining growth in production

Currently, the issue of concern is the stagnating yields of rice and wheat in the most productive regions of the IGP. To verify the emerging concern, statewise growth rates in production, area and yield of rice and wheat were computed for 1972–85, 1985–95 and 1972–95 (Tables 4 and 5). Although yields of rice and wheat were showing an increasing trend, the rate of growth in production during 1985–95 were lower in comparison to 1972–85 period in Haryana and Punjab. Annual compound growth rate of rice yield in Punjab was 4% during 1972–85, while it declined to 0.9% in 1985–95. The corresponding changes in growth rates of rice yields in Haryana were 3.7 and 0.8%. The area expansion was the major source of production growth. In other states, the yields were yet to reach the potential level, and there was still enough scope to increase yields of rice. In wheat, the yield growth rates were positive and increased to 4.2% in 1985–95 which was 2.8% in 1972–85 in the IGP. Yield increase was still a main source of increasing wheat production in all the states. Slower rate of growth in production of rice and wheat during 1985-95 as compared to 1972-85 in Punjab and Haryana is a matter of serious concern as these states contribute major share of

Table 4. Area, production and yield of rice in the Indo-Gangetic plains, India.

State	1972	1975	1985	1995	Annual growth rate(%)		
					1972–85	1985–95	1972–95
Punjab							
Production (Th t)	854	1272	5012	7371	14.8	4.0	9.7
Yield(t ha^{-1})	1.95	2.30	3.11	3.34	4.0	0.9	2.3
Area (Th ha)	439	552	1613	2206	10.8	3.1	7.4
Haryana							
Production (Th t)	486	519	1441	2048	9.8	4.3	6.4
Yield(t ha^{-1})	1.71	1.79	2.58	2.58	3.7	0.8	1.9
Area (Th ha)	284	290	558	795	6.1	3.5	4.5
Uttar Pradesh							
Production (Th t)	3584	3892	7416	10247	4.6	3.7	4.2
Yield(t ha^{-1})	0.79	0.86	1.35	1.82	3.1	3.3	3.2
Area (Th ha)	4553	4541	5482	5621	1.5	0.4	1.0
Bihar							
Production (Th t)	4631	4517	5453	6396	-1.0^{ns}	-0.3^{ns}	1.1
Yield(t ha^{-1})	0.90	0.87	1.06	1.33	-0.8^{ns}	0.9^{ns}	1.5
Area (Th ha)	5134	5222	5136	4825	-0.2^{ns}	–1.2	-0.3
West Bengal							
Production (Th t)	6121	6402	8008	12154	0.5	4.6	3.2
Yield(t ha^{-1})	1.22	1.20	1.53	2.07	0.5	3.3	2.6
Area (Th ha)	5005	5353	5217	5867	-0.0	1.3	0.6
Indo-Gangetic plains							
Production (Th t)	15664	16603	27331	38216	3.2	3.4	3.3
Yield(t ha^{-1})	1.02	1.04	1.52	1.98	2.2	2.8	2.5
Area (Th ha)	15414	15959	18006	19315	1.0	0.6	0.8

ns = not statistically significant.

Th t = thousand tonnes. Th ha = thousand hectares.

Source: Derived from Government of India (1995).

Table 5. Area, production and yield of wheat in the Indo-Gangetic plains, India.

State	1972	1975	1985	1995	Annual growth rate(%)		
					1972–85	1985–95	1972–95
Punjab							
Production (Th t)	5377	5423	9685	13214	5.1	2.9	4.5
Yield(t ha^{-1})	2.29	2.32	3.09	3.99	2.6	2.3	2.5
Area (Th ha)	2346	2330	3136	3309	2.5	0.6	1.5
Haryana							
Production (Th t)	2325	2064	4712	7294	6.1	4.7	5.8
Yield(t ha^{-1})	1.95	1.76	2.72	3.66	2.7	3.2	3.0
Area (Th ha)	1192	1174	1729	1992	3.4	1.5	2.8
Uttar Pradesh							
Production (Th t)	7585	7203	11152	21862	6.7	7.1	6.9
Yield(t ha^{-1})	1.26	1.17	1.33	2.42	3.7	6.4	5.0
Area (Th ha)	6029	6154	8399	9026	3.0	0.7	1.9
Bihar							
Production (Th t)	2296	1982	2967	4270	1.7	3.6	3.1
Yield(t ha^{-1})	1.34	1.28	1.59	2.07	0.5	2.8	1.9
Area (Th ha)	1707	1543	1867	2062	1.2	0.8	1.2
West Bengal							
Production (Th t)	826	885	802	742	–2.1	$–1.2^{ns}$	–1.8
Yield(t ha^{-1})	2.15	2.02	2.48	2.32	–0.0	0.8^{ns}	$–0.0^{ns}$
Area (Th ha)	382	439	323	319	–2.1	–2.0	–1.8
Indo-Gangetic plains							
Production (Th t)	18409	17557	29318	47383	5.4	4.9	5.2
Yield(t ha^{-1})	1.58	1.51	1.90	2.84	2.8	4.2	3.8
Area (Th ha)	11658	11639	15456	16708	2.6	0.8	1.4

ns = not statistically significant. Th t = thousand tonnes. Th ha = thousand hectares.

Source: Derived from Government of India (1995).

total food grain procurement for rest of the country.

Input Use Pattern and Cost

Changes in input use

The cost of cultivation data from the Directorate of Economics and Statistics for 1976–1992 were used to examine the changes in traditional and modern inputs in the RWCS (Tables 6 and 7). Two important features were observed while analyzing the use of traditional and modern inputs. These were: (i) use of inorganic fertilizer has remarkably increased, while that of organic sources of nutrients, namely, farmyard manure and legumes have declined, and (ii) irrigation and improved varieties have almost reached to the ceiling levels (Table 8). Almost 90% area was sown

Table 6. Annual compound growth rate(%) of traditional and modern inputs in RWCS during 1976-92.

Inputs	Punjab	Haryana	Uttar Pradesh	Indo-Gangetic plains
Traditional inputs				
Seed	0.7	0.4	–1.7	–1.4
Manure	0.3	–10.4	–10.2	–5.6
Modern inputs				
Fertilizers	3.9	3.9	5.3	5.5
Pesticides	14.8	22.9	11.0	17.2
Labor and machine				
Human labor	–2.6	–1.0	–1.5	–1.8
Animal labor	–12.9	–9.1	–5.5	–6.9
Machine labor	3.8	2.8	7.0	6.3

under high-yielding varieties, about 80% area was under irrigation and 260 kg ha^{-1} of chemical nutrients were used in rice and wheat. Fertilizer consumption in rice and wheat crops in Punjab was approaching 400 kg ha^{-1} in 1992, while in Uttar Pradesh, it was yet to cross 200 kg ha^{-1}. Sidhu and Byerlee (1992) reported that in some of the more developed districts of Punjab such as Ludhiana, fertilizer use has already exceeded the recommended dose.

Table 7. Estimated factor shares in total cost (%) of production of rice and wheat in the Indo-Gangetic plains, India.

Factor	Punjab		Haryana		Uttar Pradesh		Indo-Gangetic plains	
	I	II	I	II	I	II	I	II
Land	26	38	24	26	26	23	26	28
Seed	4	3	4	3	6	6	5	5
Human labor	24	17	22	22	22	22	22	21
Animal labor	8	1	14	31	17	10	15	6
Machine labor	5	12	5	10	4	11	4	11
Fertilizer	15	12	11	12	9	8	10	10
Manure	1	*	1	*	3	*	2	*
Pesticides	*	3	*	3	*	*	*	1
Irrigation	10	6	11	11	5	6	6	7
Interest	7	8	8	10	8	13	8	11

I = 1974–76. II = 1990-92. * = less than 0.5%.

Hence, growth in the use of fertilizer and fertilizer's marginal contribution to yield are expected to be substantially lower in future than what were realized in the past.

As seen in Table 8, the adoption of high-yielding varieties (HYVs), irrigation coverage has almost reached to a ceiling although scope still exits to adopt several newer and HYVs and follow efficent methods of using water and other critical inputs to attain higher growth in yield. In contrast to the use of HYVs and irrigation, which had reached to a high level in almost all the major RWCS areas early in the period, fertilizer use continued to increase rapidly, from about 107 kg ha^{-1} of NPK in 1976 to 259 kg ha^{-1} in 1992 – an annual growth rate of 5.5% per year. By 1992, average fertilizer use had reached over 85% of the recommended dosage in Punjab, 60% in Haryana, and about 50% in Uttar Pradesh. Use of pesticides/herbicides increased manifold in Punjab and Haryana in early 1990s as compared to 1980s, indicating the rising problem of insect pests and diseases.

In contrast to the use of inorganic fertilizers, there was a strong evidence that use of organic manure had declined substantially in the IGP. At aggregate level, it declined by about 5% annually during 1976–92, and its consumption came down to less than 2t ha^{-1} in 1992 from about 5 t ha^{-1} in 1976 (Table 8). This decline might have occurred because the cropped area has expanded much faster than the livestock numbers as bullocks have been replaced by tractors. Moreover, most of the dung is used as fuel.

The use of labor-saving technologies, especially the tractors, has expanded rapidly and substituted for human and bullock labor (Table 7). The most prominent change has occurred in use of animals; the annual growth rate has

Table 8. Use of inputs in RWCS in the Indo-Gangetic plains, India.

State	1976	1985	1992	Growth (%) 1976–85	1985–92	1976–92
Punjab						
Fertilizer (kg ha^{-1}) ($N+P_2O_5+K_2O$)	194	353	397	6.4	2.4	3.9
Irrigation (% of crop area)	91	96	98	0.5	0.3	0.4
HYV (% of crop area)	90	98	98	1.1	–0.0	0.5
Organic Material						
FYM (q ha^{-1})	45	87	40	6.7	–13.6	0.3
Legumes area (% of R&W area)	–18	6	2	–13.3	–14.8	–12.8
Haryana						
Fertilizer (kg ha^{-1}) ($N+P_2O_5+K_2O$)	161	262	336	4.9	3.5	3.9

Continued

Table 8. Concluded.

State	1976	1985	1992	Growth (%)		
				1976–85	1985–92	1976–92
Irrigation (% of crop area)	89	96	98	0.8	0.3	0.6
HYV (% of crop area)	82	92	89	1.4	–0.6	0.6
Organic Material FYM (q ha^{-1})	19	10	4	–7.5	–2.1	–10.4
Legumes area (% of R&W area)	68	33	21	–8.3	–6.8	– 7.8
Uttar Pradesh						
Fertiliser (kg ha^{-1}) ($N+P_2O_5+K_2O$)	92	152	197	5.7	3.0	5.3
Irrigation (% of crop area)	53	63	73	1.9	1.9	1.9
HYV (% of crop area)	56	76	91	3.4	2.4	3.2
Organic Material FYM (q ha^{-1})	48	29	9	–4.5	–14.7	–10.2
Legumes area (% of R&W area)	33	24	22	–3.2	–1.2	– 2.3
Indo-Gangetic plains						
Fertilizer (kg ha^{-1}) ($N+P_2O_5+K_2O$)	107	202	259	7.0	3.2	5.5
Irrigation (% of crop area)	64	74	82	1.6	1.3	1.5
HYV (% of crop area)	65	83	92	2.7	1.4	2.3
Organic Material FYM (q ha^{-1})	46	40	16	–0.7	–13.0	–5.6
Legumes area (% of R&W area)	33	21	17	–5.2	– 3.0	–4.1

Note: R&W area = Rice and wheat crop area. q = 100 kg. FYM = farmyard manure declined by as much as 13% in Punjab, followed by 9% in Haryana, and 6% in Uttar Pradesh. The human labor use has also fallen at the annual growth rate between 1 and 3% in these states. The share of bullocks in the total cost of rice-wheat production fell sharply, while that of machines (tractors, harvesters, etc) increased rapidly. The share of modern inputs in total cost has increased sustantially over the last two decades in the IGP region of India.

Real cost of production

As expected, with rapid technical change, the unit cost of production (at constant prices) of rice and wheat decreased steadily at an annual rate of 3.2% in Punjab, 2.6% in Haryana, and 2.4% in Uttar Pradesh during 1976–92 (Table 9). The unit cost of production of rice and wheat continued to decline during 1985–92. However, the rate slowed down to –1.8% in Punjab and –1.7% in Haryana, while it stagnated in Uttar Pradesh during 1985–92. The decline in unit cost of production due to technological change and input subsidies has resulted in substantial increases in the marketable surplus of wheat and rice. These contributed to food security mainly by inducing sharp decline in real prices of rice and wheat grains (down 0.7% annually, Table 10). Many of the benefits of higher efficiency in the use of inputs and lower unit costs of production that technological change has generated were shared by both farmers and consumers. The farmers gained because of higher crop yields and production, while the consumers benefited by higher purchasing power due to lower prices. The fall in prices of grains have benefited the urban and rural poor more than the upper income groups, because the former spend a much larger proportion of their income on these crops than the latter (Kumar 1997).

Table 9.Trends in indices of unit cost of rice and wheat production at constant prices in the Indo-Gangetic plains, India.

State	Index(%)			Annual growth rate (%)		
	1976	1985	1992	1976–85	1985–92	1976–92
Punjab	185.4	130.5	114.3	–4.3	–1.8	–3.2
Haryana	173.5	130.7	116.2	–3.4	–1.7	–2.6
Uttar Pradesh	159.9	119.9	118.1	–2.7	–0.0	–2.4
Indo-Gangetic plains	168.1	123.4	114.1	–3.3	–1.0	–2.9

Table 10. Trends in indices of prices per unit of rice and wheat at constant prices in the Indo-Gangetic plains, India.

State	Index(%)			Annual growth rate (%)		
	1976	1985	1992	1976–85	1985–92	1976–92
Punjab	109.3	95.7	99.2	–1.5	0.2[ns]	–1.2
Haryana	122.7	104.1	132.6	–2.0	3.1	0.2ns
Uttar Pradesh	104.5	93.7	102.0	–1.2	0.9+	–0.7
Indo-Gangetic plains	106.1	92.8	103.7	–1.3	0.9+	–0.7

+= significant at 10 % level. ns = non-significant.

Sustainability of RWCS

Measuring total factor productivity

The average annual growth rates of output, inputs and TFP indices for RWCS in the states under the IGP are given in Table 11. The results revealed that in Punjab the input index during 1976–92 has risen at the rate of 7.2%, whereas it was 4.2% in Haryana and 1.4% in Uttar Pradesh. With the increase in inputs and technological change, the output increased by 9.1% in Punjab, 5.6% in Haryana and 2.9% in Uttar Pradesh. Thus, the TFP growth rate in the RWCS was estimated at 1.9% in Punjab, 1.4% in Haryana, and 1.6% in Uttar Pradesh during 1976–92. Overall in the IGP, the input, output and TFP indices have risen annually by around 3.4, 4.9 and 1.5%, respectively. Growth in the TFP was responsible for about 21% increase in the output growth of rice and wheat in Punjab. The corresponding figures for Haryana and Uttar Pradesh were 25 and 55%. The highest growth in rice-wheat grains production during 1976–92 was attributed to higher use of inputs in Punjab followed by Haryana and Uttar Pradesh. This clearly shows that the future output growth will largely be achieved by using more inputs. However, in these states, use of

Table 11. Trends in indices of total factor productivity of RWCS in the Indo-Gangetic plains, India.

State	Index (%)			Annual growth rate (%)		
	1976	1985	1992	1976–85	1985–92	1976–92
Punjab						
Input index	47.3	137.3	172.1	10.9	3.3	7.2
Output index	35.8	134.5	177.6	14.0	4.1	9.1
TFP	75.8	97.9	103.1	3.2	0.8	1.9
Haryana						
Input index	62.9	114.2	156.1	5.3	5.2	4.2
Output index	53.0	118.4	162.2	7.7	5.1	5.6
TFP	84.2	103.7	103.9	2.4	–0.1^{ns}	1.4
Uttar Pradesh						
Input index	88.5	94.2	113.9	0.9	3.5	1.4
Output index	87.9	121.0	136.8	3.1	2.3	2.9
TFP	99.3	128.4	120.1	2.2	–1.2	1.6
Indo-Gangetic plains						
Input index	78.3	104.6	127.8	3.2	3.5	3.4
Output index	69.9	126.0	151.8	6.1	3.1	4.9
TFP	89.3	120.4	118.8	2.9	–0.4^{ns}	1.5

Note: Index numbers are the average figures for triennium ending 1976, 1985, 1992. ns = statistically not significant.

modern inputs had already reached high levels in the early period.

During 1976–85, growth in output was almost equally contributed by growth in use of inputs and the TFP. In the later period (1985–92), growth rate in the TFP for the RWCS has declined (–1.2%) in Uttar Pradesh, near stagnated (0.8%) in Punjab, and totally stagnated (–0.1%) in Haryana. Such a phenomenon has two important implications: (i) the qualitative change due to improved technology has disappeared in the IGP, and (ii) positive growth in output has been achieved as a result of input quantities. Negative and stagnating growth in the TFP is a matter of concern in the IGP. Decelaration in growth in productivity will influence the cost of production and adversely affect the profitability. Input-based yield growth may not be sustained, if further technological improvements do not occur. This emphasizes the need for identification and implementation of sustainable sources of productivity growth in the RWCS.

Role of legumes in influencing TFP

Earlier studies (Rosegrant and Evenson 1992, Kumar and Mruthyunjaya 1992, Kumar and Rosegrant 1994) show that research, extension, infrastructure, efficiency of inputs and literacy are the important sources of growth in the TFP. Historically, legumes are known to improve soil fertility. Their importance is more significant in the RWCS where organic sources of fertility improvement have rapidly declined. Ladha et al.(1996) reported following benefits of legumes in sustaining soil fertility: (i) Potential to make substantial contributions to the nitrogen economy of the cropping system; (ii) Legumes often exert favorable influences on several other soil fertility parameters through their extensive and deep root systems; (iii) Ability to extract nutrients from deep soils layers; (iv) Utilize insoluble or fixed form of nutrients like phosphorous, and make them available to the succeeding crops; and (v) Crops like *Sesbania* and their incorporation improve physico-chemical properties of saline-alkali soils, leading to increased growth and yields of subsequent crops. Joshi (1996) documented the evidence that legumes are contributing in savings of nitrogenous fertilizers and improving soil fertility. To confirm the role of legumes in the sustainability of the RWCS, legumes area is included as one of the variables in the TFP decomposition model along with a trend variables. Inclusion of trend variable was to capture the aggregate effect of research stock, expenditure on extension, infrastructure and literacy etc, on the TFP. The estimated TFP decomposition equation for the RWCS in the IGP is given below:

$$\ln TFP = \underset{}{3.71252} + \underset{(3.98)}{0.13820^{**}} \ln IALEG + \underset{(5.68)}{0.04445^{**}} T - \underset{(2.81)}{0.00107^{**}} TT$$

Adjusted R^2 = 0.59

where, ln: Natural Logarithm; TFP: Index of TFP of RWCS; IALEG:Index of legumes area; T: Trend variable (starting from 1973); TT: Square term of trend variable. Figure in parentheses are the student t statistics; **: Significant at 1% probability level.

The effect of legumes area on the TFP of RWCS is positive and highly significant which suggested that the role of legumes is of crucial importance for the growth in productivity and for sustaining the RWCS in the IGP. Legumes production may be encouraged to improve the sustainability of rice and wheat crops in the IGP.

Despite the positive influence of legumes in the TFP of the RWCS, the area under legumes has substantially declined in the IGP of India. In the early 1990s, legumes occupied slightly more than 5 million ha in the Indian region of the IGP (Table 12). Nearly 3 million ha area under grain legumes has declined during the last two decades as it was substituted by other crops, largely rice and wheat. Persistent fall in the area under grain legumes during the last decade was mainly due to relatively higher profitability of rice and wheat (Table 13). Farmers of the IGP responded favorably to better technologies, remunerative prices and assured market of rice and wheat in contrast to the legumes.

Improved technologies for legumes production are now available but their adoption is not visible. For example, extra short-duration pigeonpea varieties are now available which can very well fit in a rotation with wheat (Singh et al. 1996). Efforts are also in progress to find appropriate cytoplasmic male sterile lines in pigeonpea to develop hybrid for higher production potential. Similarly, black gram and green gram are becoming popular as catch crops in the IGP. Some short-duration varieties of chickpea are also released for cultivation in the IGP but they have problem of instability in yields due to high incidence of insect pests and diseases. Ironically, farmers do not have sufficient information about the new varieties which suit their requirements to improve the sustainability of the RWCS. The public and private seed sectors are not giving due priority to produce and market enough seed of improved varieties of legumes. Appropriate demonstration by the state departments of agriculture should be toned-up to educate farmers about long-term beneficial role of legumes in improving the sustainability of the RWCS in the IGP.

Conclusions

The RWCS is spread in the most fertile regions covered by the IGP. In India, this system is predominant in the states of Punjab, Haryana, and Uttar Pradesh. Three-fourths of the total rice area and more than half of the wheat area is under the RWCS. This production system contributes about one-third to India's total cereal production. As high as 95% of the wheat procurement, and 60% of the rice procurement comes from the RWCS of the IGP. The sustainability of the RWCS in the IGP is critical for the country's public distribution system and food security.

Share of the TFP (used as a measure of sustainability) in the growth rate of rice and wheat production is declining. The yield growth is more input based. The use of modern inputs (for example, adoption of high-yielding varieties, irrigation, chemical fertilizers, pesticides, etc.) in the IGP has already been achieved to a high

Table 12. Area under principal legumes in the Indo-Gangetic plains, India.

Crop	Area ('000ha)			Annual growth rate (%)	
	1969–72	1979–82	1989–92	1970–80	1980–90
Chickpea	3958	2838	1958	– 3.3	– 3.6
Pigeonpea	717	662	635	– 0.8	– 0.4
Other pulses	2960	2400	2546	– 2.1	0.6
All pulses	7635	5900	5139	– 2.5	– 1.4
Groundnut	531	335	182	– 4.5	– 5.9
All legumes	8166	6228	5296	– 2.7	– 1.6

Table 13. Profit from rice, wheat and legumes in the Indo-Gangetic plains, India.

State	Crop	Period	Price (Rs/q)	Profit (Rs/ha)	Real profit (grains in q/ha)
Punjab	Paddy	1974–76	75	503	6.7
		1980–82	112	2476	22.1
		1990–92	256	7510	29.3
	Wheat	1974–76	110	1381	12.6
		1980–82	140	2091	14.9
		1990–92	280	7182	25.7
	Paddy	1974–76	85	854	10.0
		1980–82	114	2202	19.3
		1990–92	380	8831	23.2
	Wheat	1974–76	112	1355	12.1
		1980–82	138	1663	12.0
		1990–92	286	7748	27.1
	Chickpea	1980–82	282	533	1.9
		1990–92	693	2887	4.2
Uttar Pradesh	Paddy	1974–76	72	539	7.5
		1980–82	114	965	8.5
		1990–92	253	3550	14.0
	Wheat	1974–76	111	1222	11.0
		1980–82	147	1556	10.6
		1990–92	309	5367	17.4
	Black gram	1984–86	334	1127	3.4
		1990–92	708	1923	2.7
	Pigeonpea	1984–86	382	4144	10.8
		1990–92	799	7458	9.3
	Green gram	1984–86	219	617	2.8
	Chickpea	1984–86	338	2065	6.1
Bihar	Paddy	1974–76	100	1068	10.7
		1980–82	175	1958	11.2
		1990–92	246	2576	10.5
West Bengal	Paddy	1974–76	100	1074	10.7
		1980–82	161	2113	13.1
		1990–92	254	3788	14.9

q = 100 kg.

level. The organic sources of nutrients, like organic manure and legumes area, are rapidly declining in the RWCS. Further scope of increasing yield of rice and wheat from modern inputs and area expansion seems to be remote. Higher growth in yield and production of the RWCS can only be achieved through better management of existing soil and water resources.

Despite the positive effect of legumes in the TFP of the RWCS, their area has substantially declined as these were substituted by rice and wheat. Persistent fall in the legumes area was mainly due to relatively higher profitability of the substitute crops. Improved high-yielding and short-duration varieties of legumes are now available but their adoption is very slow in the RWCS. More remunerative prices, better procurement mechanism of legumes, adequate support by public and private seed sector may encourage farmers to incorporate legumes in the RWCS. These should be supported by creating awareness among farmers about the sustainability issues of the RWCS and the role of legumes. Demonstrations of high-yielding and short-duration legume varieties are required to encourage farmers to grow legumes to improve the soil fertility status for enhancing the sustainability of the RWCS.

References

Abrol, I.P. 1996. Rice-wheat consortium for the IGP- the rationale. *in:* international symposium on sustaining rice-wheat cropping system–emerging research agenda, New Delhi, Rice-Wheat Consortium for the Indo-Gangetic Plains.

Chaudhary, M. K. and **Harrington, L.W.** 1993. The rice wheat system in Haryana: input-output trends and sources of future productivity growth. Karnal and Mexico, D.F., C.C.S. Haryana Agricultural University Regional Research Station, and CIMMYT.

Diewert, W. E. 1976. Exact and superlative index numbers. Journal of Econometrics 4:115–145.

Ehui, S.K. and **Spencer, D.S.C.** 1990. Indices for measuring the sustainability and economic viability of farming systems. Research Monograph No. 3. Resource and Crop Management Program, ICRISAT, Patancheru, India: International Crops Research Institute for the Semi-Arid Tropics (limited circulation).

Evenson, R.E. and **Jha, D.** 1973. The contribution of agricultural research system to agricultural production in India. Indian Journal of Agricultural Economics 28(4):212–30.

Government of India. 1995. Area and production of principal crops in India. Directorate of Economics and Statistics, New Delhi, Ministry of Agriculture.

Government of India. 1996. Economic survey, Ministry of Finance, New Delhi.

Jha, D. and **Kumar, Praduman** 1996. Impact of rice research in India. Paper presented in the second International Conference on Impact of Rice Research, 3–5 June, jointly organised by the Thailand Development Research Institute and IRRI at Bangkok. (limited circulation).

Joshi, P.K. 1996. Performance of grain-legumes in the IGP. Paper presented in the workshop on Residual Effects of Legumes in Rice-Wheat Cropping System in the IGP, 26–28 August 1996, ICRISAT, Patancheru, (limited circulation).

Kumar, Praduman and **Mruthyunjaya** 1992. Measurement and analysis of total factor productivity growth in wheat. Indian Journal of Agricultural Economics 17(3):451–458.

Kumar, Praduman and **Rosegrant, Mark W.** 1994. Productivity and sources of growth in rice:

India. Economic and Political Weekly 29(53):A 183–188.

Kumar, Praduman and **Mathur, V.C.** 1996. Agriculture in future: demand-supply perspective for the ninth Five-Year Plan. Economic and Political Weekly 31(39):A131–139.

Kumar, Praduman 1997. Agricultural productivity and food security in India: implications for policy. Agricultural Economics Research Review 9(2):1–13.

Ladha, J.K., Kundu, D.K., Coppenolle, M.G.A. Peoples, Carangal, V.R. and **Dart, P.J.** 1996. Legumes productivity and soil nitrogen dynamics in lowland rice-based cropping systems. American Journal of Soil Science Society 60:183–192.

Lynam, J.K. and **Herdt, R.W.** 1988. Sense and sustainability: sustainability as an objective in international agricultural research: *in* a Conference on Farmers and Food Systems, organized jointly by CIP-Rockefeller, Lima, Peru, CIP.

Paroda, R. S. 1996. Sustaining the green revolution: New paradigms. In B.P. Pal Commemoration Lecture. *in:* 2nd International Crop Science Congress, 22 Nov. 1996, New Delhi.

Ramesh Chand and **Haque, T.** 1998. Rice-wheat crop system in Indo-Gangetic region-issues concerning sustainability. Economic and Political Weekly 33(26): A108–112.

Rosegrant, Mark W. and **Evenson, R.E.** 1992. Agricultural productivity and sources of growth in South Asia. American Journal of Agricultural Economics, 74:757–61.

Sidhu, D.S. and **Byerlee, D.** 1992. Technical change and wheat productivity in the Indian Punjab in the post-green revolution period. Working Paper 92–02, Economics, Mexico, D.F., CIMMYT.

Singh, L., Chauhan, Y.S., Johansen, C. and **Singh, S.P. (eds.)** 1996. Prospects for growing extra-short duration pigeonpea in rotation with winter crops. Patancheru, and New Delhi: International Crops Research Institute for the Semi-Arid Tropics, and Indian Agricultural Research Institute.

Whitaker, M. and **Lalitha, S.** 1993. Quantifying the relative productivity and sustainability of alternative cropping systems. Progress Report No. 115. Resource Management Program, Economics Group, ICRISAT, Patancheru, India, International Crops Research Institute for the Semi-Arid Tropics.

Technological Change and Productivity in Pakistan's Punjab: Econometric Evidence

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Abstract

This paper addresses the critical issue of long-term productivity and sustainability of Pakistan's irrigated agriculture. District-level data was assembled on 33 crops, 8 livestock products, and 17 input-types and qualities to estimate changes in total factor productivity in four productivity systems. Average growth in total factor productivity was moderately high at 1.25% for both crops and livestock but wide regional variation in productivity growth was observed with negative growth in the wheat-rice system. A second disaggregated data set on soil and water quality was then used to analyze underlying effects of resource degradation through application of a cost function. The continuous and widespread resource degradation as measured by the soil and water quality variables had a significant effect on productivity with the largest effect being in the wheat-rice system. The results call for urgent action at both the technological level and the policy level to arrest the degradation and to enhance the pace of technological changes, as past sources of productivity growth have largely been exhausted.

Introduction

The introduction of Green Revolution technologies in wheat and rice in Pakistan in the mid-1960s produced impressive results in reversing the food crisis and stimulating agricultural and economic growth. However, questions are now being asked about the sustainability of this intensification strategy, in the light of high use of external inputs, growing evidence of a slowdown in productivity growth (Byerlee 1992), and degradation of the resource base (Faeth 1993).

These concerns are based upon research which first showed declining yields under intensive conditions in long-term experiments (Flinn and De Datta 1984). Scientists later observed stagnating yields in farmers' fields in relation to growing input use, where intensive cereal-cereal culture had been continuously practiced (Cassman and Pingali 1995, Ali 1996, Byerlee and Siddiq 1994). These problems were considered especially important in the rice-wheat belt, the breadbasket of northern India and Pakistan which covers over 12 million ha and provides food security for a large population (Hobbs and Morris 1996).

Nonetheless there is little quantitative evidence to date of the lack of sustainability of current intensification strategies. Part of the problem has been the difficulty of agreeing on useful measures of sustainability. Lynam and Herdt (1989) proposed a non-positive trend in total factor productivty (TFP) as a good indicator of lack of sustainability due to resource degradation. This measure raises an additional set of issues, such as the level (e.g. crop or system) at which TFP should be measured, whether inputs should include changes in

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resource quality, and if so, how are those changes to be valued? Recent evidence of changes in TFP in Pakistan, for example, provide indefinite results from negative (Ali and Valesco 1993) to significantly positive (Khan 1994) trends in TFP. Moreover, it is not necessary (perhaps nor possible) to maintain resource quality for all system components, in all locations (Lynam and Herdt 1989). Farmers may avoid resource degradation by exploiting substitution possibilities among inputs and crops. Finally, a positive trend in TFP does not necessarily imply sustainability since productivity gains from new technologies may mask the effects of resource degradation, at least in the short- to medium-term.

The main objectives of this study is to observe TFP at the production system level in the period since the advent of the Green Revolution, in order to consider these substitution possibilities. The second objective is to relate productivity trends to changing resource quality. Earlier studies have estimated resource productivity at the national level (Khan 1994), or restricted to one crop in a region. I think this study is at the farm-level (Cassman and Pingali 1995). Since sustainability is likely to relate to underlying agronomic and socio-economic characteristics of the farming or production system, such as crop rotation, a major contribution of this study is to quantify trends in resource productivity at the production system level defined in terms of major crops and livestock enterprises in the system. Considerable resources were invested in collecting the large amount of data on individual crop and livestock products, inputs, and prices that are required for the system-level analysis.

Further, in order to econometrically relate trends in productivity to indicators of resource quality, we establish a second comprehensive data base on changes in soil and water test variables at the district level. This enables us to at least partially separate the effects of technological, human resource and resource quality variables on productivity.

This study focuses on the measurement of agriculture productivity change in the irrigated agriculture of Pakistan's Punjab province which is the agriculturally dominant province in the country with a farming population of over 60 million and often described as Pakistan's bread basket. Over 80% of the cropped area of the province is irrigated. The Punjab was one of the earliest beneficiaries of the Green Revolution with the introduction of modern varieties of wheat and rice in the 1960s. However, growth of rice and wheat yields have slowed in the past decade and recent studies have questioned the sustainability of current intensification strategies (Byerlee and Siddiq 1994). With record imports of its staple food in recent years, the issue is clearly critical to agricultural development strategies in Pakistan.

The paper is organised as follows. The following two sections outline the analytical approach and the major data sources. This is followed by a description of major trends in the agricultural sector, especially those related to technical change and resource quality. Estimates of TFP growth are then presented relationship between productivity and resource quality econometrically estimated through a cost function.

Analytical Approach

Several methods of measuring changes in resource productivity can be applied depending upon the objectives, circumstances under which these estimations are made, and availability of data. If inputs and technology remain constant, as is the case under experimental conditions, simple yield trends can indicate changes in the natural productive capacity of land. At the regional or national level, higher input use combined with declining or stagnant yields will also reflect declining factor productivity. However, the reverse is not true: rising yields are not an indication of a positive trend in TFP.

Following Lynam and Herdt (1989), a non-positive trend in TFP has been widely accepted, at least by economists, as an indicator of unsustainable resource management (Cassman and Pingali 1995, Ehui and Spencer 1993). However, many practical problems are encountered in choosing an acceptable measure of TFP. For example, Squires (1991) included conventional inputs only, while the resource stock, such as soil nutrient content, was considered as a technical constraint, so that the deterioration in the stock of these resources is reflected in a downward shift of TFP. Anderson, Alston and Pardey (1996) have proposed a measure of social TFP that values changes in resource quality. An attempt to apply this approach is provided by Ehui and Spencer (1993).

This study applies the Squires approach so that changes in resource quality are reflected in a shift in TFP. Estimated in this way, the trend in TFP is the sum of: (i) technological progress, (ii) changes in resource quality, and (iii) improvement in technical and allocative efficiency due to human and physical infrastructure. Although the approach avoids the complication of valuing the resource stock, this measure of TFP will mask resource degradation as long as productivity increases due to technological change, and efficiency gains are more than any decline due to resource degradation. To decompose trends in productivity growth, we then relate productivity to variation in resource quality over space and time, human resources, and technological variables. This enables a system specific estimate of the effects of changes in resource quality on productivity.

The chain-linked Tornqvist-Theil indexing procedure is commonly used to measure TFP because it is exact for a flexible linear homogeneous translog aggregate production function (Diewert 1976). The index is estimated as follows:

$$\ln\left(Q_t/Q_{t-1}\right)=\frac{1}{2}\sum_{i=1}^{m}\left(s_{it}+s_{it-1}\right)\ln\left(q_{it}/q_{it-1}\right)$$

$$\ln\left(X_t/X_{t-1}\right)=\frac{1}{2}\sum_{z=1}^{n}\left(s_{zt}+s_{zt-1}\right)\ln\left(x_{zt}/x_{zt-1}\right) \text{ , and} \quad (1)$$

$$\ln\left(TFP_t/TFP_{t-1}\right)=\ln\left(Q_t/Q_{t-1}\right)-\ln\left(X_t/X_{t-1}\right)$$

where q_{it} is the quantity of the *i*th output ($i=1,2,\ldots m$ number of product types) in the *t*th period ($t=1,2,\ldots$ T number of years); x_{zt} is the quantity of the *z*th input ($z=1,2,\ldots n$ number of inputs) in the *t*th period; $\ln(Q_t / Q_{t-1})$ and $\ln(X_t / X_{t-1})$ are the weighted rate of change in all outputs and inputs, respectively; and s_{zt} and s_{it} are respectively the share of the *z*th input in total costs and of the *i*th output in total value of production.

The index can be estimated for one output and all related inputs (enterprise factor productivity, EFP), or all outputs and one input (partial factor productivity, PFP) and all inputs and outputs (total factor productivity, TFP). This study estimated the PFP for important inputs (labor, water, and land), EFP for crops and livestock, and TFP.

The effect of resource quality on productivity can be econometrically tested through a production function, profit function or a cost function. The cost function has the advantage of avoiding simultaneity bias inherent in the production function. The profit function suffers from the disadvantage that many data points have negative profit, which cannot be included in a logarithmic function. The cost function in translog form[1] can be expressed as:

$$\ln C = \alpha + \sum_{i=1}^{m}\alpha_i \ln q_i + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m}\beta_{ij}\ln q_i \ln q_j + \sum_{z=1}^{n}\chi_z \ln w_z$$
$$+ \frac{1}{2}\sum_{z=1}^{n}\sum_{u=1}^{n}\chi_{zu}\ln w_z \cdot \ln w_u + \sum_{i=1}^{m}\sum_{z=1}^{n}\delta_{iz}\ln q_i \cdot \ln w_z$$
$$\sum_{o=1}^{r}\phi_o \ln S_o + \sum_{f=1}^{q}\gamma_f \ln H_f + \sum_{r=1}^{k}\lambda_r T_r$$
$$+ \sum_{c=1}^{p}\mu_c I_c + \sum_{d=1}^{l}\nu_d D_d \qquad (2)$$

where C is total cost, q_i is output, w_z is the price of zth input, S_o are resource quality-related variables (such as organic matter content in soils), H_f are human and infrastructure-related variables (such as literacy rate, and distance from road, etc.), I_c are variables related to technological innovations (such as proportion of modern variety area). T_r is an annual index of time for production system *r*, and D_d is a dummy variable for district *d*. The effect of technological change on cost is controlled through the coefficient μ (expected to be negative), the changes in resource quality are measured through ϕ (expected to be positive in case of resource degradation, and negative otherwise), and the effect of improvement in human and infrastructure variable on productivity is estimated through γ (expected to be negative). The time trend variable *T* is included to estimate system-specific trends in technology, resource quality or efficiency, not captured by the above variables.[2]

Data Sources

All data were collected at the district level which were then aggregated to the production systems for purposes of computing TFP. The study includes 16 districts (as defined in 1965) each have more than 50% irrigated area, all accounting for over 90% of agricultural production in the Punjab. Production systems were defined based on: (i) cropping intensity, and (ii) the major summer (or *kharif*) crop during. 1980-81. Wheat is the dominant winter (or *rabi*) crop everywhere. Thus the province was divided into four systems: (1) wheat-mungbean, (2) wheat-rice, (3) wheat-mixed summer crops (often maize or sugarcane), and (4) wheat-cotton. These systems represent quite different agronomic types from a cereal-legume system (likely to be sustainable) to a continuous cereal cropping system (hypothesised to be less sustainable). Livestock are important in all systems, especially cows and buffaloes for milk and meat.

Data were collected from secondary sources and the Statistical Division of the Federal Ministry of Food and Agriculture, at a high level of detail by district for 1966-94. The study includes 33 crops, 8 livestock products, 6 crop by-products, and 17 input categories. Inputs and outputs were valued at farmgate harvest prices, also collected or estimated at the district level.

Input categories for the crop sector included land, labor, water, machinery (separately for tractor, thresher, and harvester), bullock, fertiliser (separately for nitrogen, phosphorus, and potash), and pesticide costs (separately for aerial and ground spray), and for the livestock sector, labor, fodder and feed, and interest and maintenance costs (shed, medicine, and other costs).[3] All inputs were converted to flow values. Land was evaluated at its rental value. Labor stocks were converted into a flow variable by multiplying the stock value with a year-and gender-specific participation rate (number of days labor used in agriculture in a year) based on household survey data collected annually by the Punjab Economic Research Institute (PERI). Similarly, machinery was valued by decomposing costs into interest on capital, and labor, fuel, shed and maintenance costs based on annual utilisation rates.

Changes in the quality of inputs are often confounded with changes in TFP (Alston, Pardey and Norton 1995). To avoid this problem: (i) labor was disaggregated into skilled and unskilled labor based on the rural literacy rate in each district; (ii) land was divided into irrigated and unirrigated land; and (iii) water into canal and tubewell water. The price of each input-quality types were separately estimated based on annual surveys by PERI. This high level of disaggregation resulted in a much richer data set than previously employed for analysis of productivity trends in Punjab.

Finally, variables on resource quality based on soil and water testing were collected from the Punjab Soil Fertility Department. These variables represent the average values from hundreds of soil tests (organic matter, phosphorus content, pH, and soluble salts) conducted by the department for scientists and farmers in each district in each year. While not strictly a random sample, we have no reason to believe there will be systematic biases by district or over time. Similarly, there has been considerable concern about secondary salinity and sodicity caused by use of low quality tubewell water (Siddiq 1995, Byerlee and Siddiq 1994). This was captured by a similar data set on tubewell water test value (residual carbonate and electroconductivity) by district and year.

The analysis was divided into three periods corresponding to different phases of Green Revolution technical change (Byerlee 1992): (i) the Green Revolution (GRR) period of 1966–74, when modern varieties were widely adopted with associated inputs, (ii) the input-intensification (INI) period of 1975–84, when input use increased rapidly, and (iii) a post-Green Revolution (PGR) period of 1985–94 when input use leveled off.

Table 1. Physical and human resource base, size of holding, and land ownership type by region and period in the irrigated Pakistan's Punjab in 1971, 1981 and 1991.

	Year	Wheat-mix	Wheat-rice	Wheat-cotton	Wheat-mungbean	Punjab
Farm size (ha)	1971	5.0	4.5	5.4	7.1	5.3
	1981	4.5	3.9	4.9	6.5	4.8
	1991	3.5	3.1	3.8	5.0	3.7
Rented land (%)	1971	46.6	44.5	50.5	44.7	45.4
	1981	35.0	37.6	40.9	36.2	36.0
	1991	27.9	27.4	32.2	28.8	28.0
Literacy (%)	1971	23.6	16.7	23.3	17.6	22.9
	1981	30.6	21.6	30.2	23.6	29.4
	1991	35.1	20.6	33.3	25.6	30.7
Distance from paved road (km)	1971	5.5	9.4	6.0	6.9	6.8
	1981	3.5	9.0	4.0	4.2	4.8
	1991	1.7	2.8	2.1	1.7	2.0

Major Trends in Punjab's Agriculture

The major characteristics of Punjab agriculture are described in Table 1. Farm size which now averages 3.7 ha has continuously declined over the past three decades, with an increasing share of that land farmed by the owner. At the same time, human resource investments and infrastructure have steadily improved over this period; however, rural literacy remains very low.

Changes in the crop subsector

Crop growth in Punjab has largely been through intensification. Land area has increased at only 0.7% annually since 1966. Technological change in Pakistans' Punjab agriculture was triggered by the introduction of modern varieties (MV) of wheat in 1967 which covered almost all wheat area by 1983. MVs of rice were also adopted but were limited by farmers' specialisation in high-valued aromatic Basmati rice varieties produced largely for the export market. However, an improved high-value rice variety (Basmati 385) was released in 1985 and rapidly adopted (Sharif et al. 1987). Similarly, new high-yielding cotton varieties were widely adopted in the post-Green Revolution period.

Use of modern varieties stimulated rapid input intensification (Table 2). Fertilizer use

Table 2. Input use in the crop and livestock sectors by cropping region and period in Pakistan's Punjab, 1965-94

Region	Period	Crop sector (ha^{-1}) Fertilizer (kg)	PP (%)	Labor (days)	Bullock (days)	Machine (hr)	Water (acre ft) TW	Water (acre ft) Canal	Irrigated area (%)	CI	Livestock (SAU^{-1}) Labor (days)	Feed & fodder (t)	Others (Rs)
Wheat-	1	6.1	11.1	82.4	83.8	0.8	0.6	3.5	59.7	104.3	30.2	2.07	45.9
mungbean	2	26.0	16.6	86.4	45.8	2.6	1.4	3.2	61.5	109.3	35.2	2.42	54.3
	3	49.1	25.3	62.6	8.0	9.1	2.0	2.9	67.0	117.8	30.5	2.51	59.5
Wheat-	1	14.1	18.2	89.5	74.4	1.4	1.1	4.9	81.0	113.4	35.8	3.19	50.9
mix	2	46.0	24.6	108.4	45.6	6.0	1.9	4.6	85.2	130.0	41.5	3.87	60.4
	3	76.0	23.9	84.6	10.8	14.7	2.5	4.2	84.7	132.4	42.5	4.11	61.9
Wheat-	1	12.3	18.9	73.6	72.9	1.6	2.8	2.6	74.0	132.4	32.6	3.50	52.5
rice	2	44.8	28.3	88.7	38.1	7.1	5.0	2.5	85.2	139.5	37.8	3.80	62.4
	3	64.7	13.4	69.4	6.5	15.7	6.0	2.1	88.6	147.4	40.3	4.13	63.3
Wheat-	1	18.5	21.3	87.2	85.4	1.7	1.5	5.9	97.2	120.6	33.6	4.07	49.6
cotton	2	62.3	35.6	100.7	49.6	6.4	2.4	5.4	98.1	128.1	35.6	3.91	58.6
	3	120.3	70.2	65.8	7.7	17.3	2.6	4.8	98.4	146.9	34.5	3.66	61.9
Punjab	1	14.1	18.3	85.0	79.6	1.5	1.4	4.7	81.9	116.9	33.8	3.40	50.0
	2	48.3	27.9	98.7	45.8	5.7	2.5	4.3	85.1	126.4	37.9	3.70	59.1
	3	86.1	40.1	71.1	8.5	14.8	3.0	3.9	86.3	136.2	37.4	3.70	61.7

The figures in parenthesis ( ) indicate growth rate in the parameter value during overall study period. All growth rates, except those bearing ns are statistically significant at least at the 10% level.

()=overall period (1966-94). 1=GRR period (1966–74). 2=INI period (1975–84). 3=PGR period (1985–94).
SAU = standard animal unit. TW = Tubewell. CI = crop intensity

jumped from 1.5 kg of nutrient per ha of cropped area in 1966 to 94 kg per ha in the post 1994 period. Pesticide use also increased rapidly, especially for cotton in the post-Green Revolution period.

The third major input was irrigation water. Although Punjab is largely irrigated, total supply of water and its timely availability have been greatly improved through investment in tubewell water (largely private), especially during the Green Revolution period. The wheat-rice system is most dependent on tubewell water.

Intensification resulted in considerable changes in labor use (Table 2). Firstly, the Green Revolution technology increased the demand for labor so that average labor use for crops increased from 71 labor days per ha in 1966 to 108 labor days in 1977 (more than 40% increase). However, the additional labor demand together with other demands, notably from the Middle East, pushed the wage rate up and induced the adoption of mechanical technology. This decreased the labor use for crops from 108 labor days in 1977 to 63 labor days in 1994. At the same time, mechanical power (tractor, harvester, and thresher) increased from less than an hr in 1966 to 17 hr per cropped ha in 1994. Meanwhile bullock use decreased dramatically from 82 days to 6 days per ha during the respective period.

The yield of all crops in the province increased at an average rate of 1.8% per annum led by wheat and cotton. The highest yield gain occurred in the Green Revolution period. The introduction of short-duration varieties of major crops, supported by increased water availability triggered double crop cultivation on the same land. Overall increase in cropping intensity was about 30% during 1966–94.

The production of all crops in the province increased at the rate of 3.3% per annum during the study period, slightly higher than the rate of population growth. The rate of growth was highest in the Green Revolution period at 3.8% per annum, and then declined to 2.8% as yield growth in wheat slowed sharply. In the post-Green Revolution period largely due to rapid increases in cotton yields, and release of new early-maturing mungbean, production growth increased slightly to 3.0% per year. There were also significant differences in performance by production system. Growth in the wheat-cotton and wheat-mungbean systems was double than that of the wheat-rice system.

Changes in the livestock subsector

Changes in the livestock technology were less spectacular with some increases in labor and fodder use. The number of animal units increased at the rate of 1.5% per annum and due to replacement of bullocks by tractors, non-milking cows including bullocks were substituted by milking cows and especially buffaloes. Changes in the livestock sector across region were not uniform, although they were less varied than those in the crop sector.

Livestock production increased even at about the same rate as for crops (3.4%), although causes of this increase are less apparent than in the crop sector. The growth rate in all livestock outputs jumped sharply in the post-Green Revolution period. The major jump occurred in the milk production which is due in part to the substitution of bullocks with milking cows in this period. The high growth in meat production during the later periods was mainly because of the slaughtering of bullocks for replacing bullock power with mechanical power.

Trends in resource quality

There are strong indications that soil and water quality in the province is deteriorating (Table 3). For example, average soil organic matter was already lower than 1% during the early 1970s, and this has further deteriorated since then in all the production systems at an average annual rate of 2.4% or a decline of 50% over the study period. The rate of decrease was highest in the wheat-rice system. Available phosphorus has also decreased in all systems at about the same rate. Total soluble salts, and pH each have increased significantly in two of the four systems

Similarly, the data confirm the deterioration in tubewell water quality, reflected in a significant increase in residual carbonate and electroconductivity of tubewell water in all production systems. Residual carbonate doubled during the study period, reflecting the common observation that farmers are increasingly tapping poorer quality groundwater.

Trends in total factor productivity

Table 4 summarizes various measures of productivity. Both land and labor productivity have increased at about 2.5% annually. Land productivity has risen more slowly since the boost during the Green Revolution period, while labor productivity has generally increased in successive periods due to rapid mechanization. An important result is the decline in water productivity, which reflects inefficient use of irrigation water partly due to price subsidies on canal water and fixed rates on electricity used for tubewells (Faruqee 1995).

Table 3. Average values[a] and percentage per annum change in selected water and soil quality parameters by period and region in Pakistan's Punjab during 1971–82 and 1983–94.

Region	Period	Residual carbon	Electroconductivity	Residual carbon	Soil pH	Organic matter	Soluble salts
Wheat-mungbean	1971–82	1.3	974.4	5.8	8.5	0.7	0.4
	1983–94	1.9	1130.5	4.9	8.5	0.5	0.4
Per annum change (%)	1971–94	3.6	1.2	–2.1	0.0[ns]	–2.5	–0.1
Wheat-mix	1971–82	1.7	948.4	5.3	8.3	0.7	0.3
	1983–94	2.7	1166.1	4.9	8.4	0.6	0.4
Per annum change(%)	1971–94	4.4	1.9	–1.0	0.1	–1.9	2.9
Wheat-rice	1971–82	1.5	817.4	6.7	8.1	0.8	0.4
	1983–94	2.6	903.9	4.7	8.5	0.6	0.4
Per annum change(%)	1971–94	4.8	0.8	–3.1	0.4	–2.7	0.5[ns]
Wheat-cotton	1971–82	2.3	1072.4	6.2	8.5	0.7	0.4
	1983–94	3.0	1197.1	4.9	8.4	0.5	0.4
Per annum change(%)	1971–94	2.3	1.1	–2.5	-0.1	–2.4	0.7
Overall Punjab	1971–82	1.7	953.1	6.0	8.4	0.7	0.4
	1983–94	2.6	1099.4	4.9	8.4	0.6	0.4
Per annum change(%)	1971–94	3.7	1.3	–2.2	0.1[ns]	–2.4	0.6[ns]

a = The average values for a region and for the Punjab was estimated by taking a simple average of the district values.
ns = the coefficient in the log linear trend function is not significant at least at the 5% level.

The overall growth in TFP for the crop sector was 1.26% per annum, contrary to most views, TFP increased little in the Green Revolution period due to high investments, especially in tubewells, and was most rapid in the post-Green Revolution period.[4] There have also been sharp differences by region with the highest rate of growth in TFP in the wheat-cotton and wheat-mungbean systems. Both systems experienced rapid growth in the post-Green Revolution period due to successful technological innovations (especially new cotton and mungbean varieties). By contrast, the wheat-rice system experienced a significant negative growth in TFP over the study period. These results confirm widespread concern that continuous double cropping of cereals, especially rice and wheat which require very different soil and water management practices, is an unsustainable cropping pattern (Fujisaka 1994, Hobbs and Morris 1996). Deterioration in soil and water quality, discussed earlier, seems to be especially serious in this system.

Growth in TFP for livestock was similar to the crop sector (1.25% per annum) but almost

Table 4. Growth rate (%) in partial inputs, sectoral output, and TFP indices by production system

Region/ State	Period	Partial productivity			Crop			Livestock			Overall
		water	land	labor	output	input	TFP	output	input	TFP	TFP
Wheat-	ALL	–3.49	1.89	3.08	3.68	2.36	1.32	4.40	2.46	1.93	1.98
mung	GR	–7.85	4.36	0.95	6.79	4.55	2.25	1.50	3.08	–1.59	1.61
bean	IN	–2.81	–1.26	0.70	1.31 ns	2.02	–0.70	4.73	3.08	1.64	0.46 ns
	PG	–0.48	3.68	7.70	4.80	1.56	3.24	5.46	1.66	3.80	4.03
Wheat-	ALL	–1.90	2.09	1.51	2.29	1.42	0.87	2.79	2.01	0.78	1.00
mix	GR	–3.08	2.54	–5.09	3.35	4.46	–1.12 ns	2.77	3.57	–0.80 ns	–0.90 ns
	IN	–1.50	3.51	1.67	2.25	0.75	1.50	1.47	1.46	0.01 ns	1.10
	PG	–0.90	0.02	2.66	1.87	1.40	0.46 ns	4.80	2.66	2.14	1.28
Wheat-	ALL	–3.03	0.89	1.03	1.79	2.30	–0.50	2.70	2.00	0.70	0.11
rice	GR	–7.31	0.76	–2.11	3.44	5.88	–2.43	2.86	3.59	–0.72 ns	–1.77
	IN	–3.65	0.88	0.80	1.24	1.84	–0.60	1.19	1.07	0.12 ns	–0.37 ns
	PG	0.14	1.85	3.01	2.04	1.17	0.88	5.17	3.04	2.13	1.87
Wheat-	ALL	–0.25	2.98	3.44	3.65	2.08	1.57	3.75	1.92	1.82	1.94
cotton	GR	–4.99	3.18	–1.81	3.66	3.96	–0.30	3.10	1.72	1.38	0.09 ns
	IN	0.10	2.32	3.48	3.55	1.77	1.79	3.06	2.20	0.87	1.87
	PG	1.96	2.90	4.30	2.70	0.92	1.77	5.36	2.55	2.81	2.32
Punjab	ALL	–1.41	2.43	2.51	3.23	1.97	1.26	3.30	2.05	1.25	1.51
	GR	–5.14	2.75	–2.85	4.00	4.49	–0.49 ns	2.75	2.82	–0.07 ns	–0.17 ns
	IN	–1.29	2.22	2.33	2.77	1.50	1.27	2.39	1.92	0.47 ns	1.21
	PG	0.61	1.96	4.14	2.85	1.25	1.60	5.15	2.53	2.62	2.25

All the coefficients, expect those bearing ns sign, are statistically significant at least at the 10% level.
ALL=1966-94. GR=1966-74. IN=1975-84. PG=1985-94.

all of this productivity growth occurred in the post-Green Revolution period. There were no significant technological innovations in livestock but improved fodder supply, substitution of milk animals for draft animals and the one-time slaughter of draft animals explain this jump in TFP. However, these sources of livestock productivity may not be available in future. Combined crop and livestock TFP grew at 1.51% per annum, higher than for the crop or livestock sector alone, suggesting complementarity in the growths of individual sectors.

Productivity and resource quality: econometric results

As concern related to resource productivity is usually directed to the crop sector, which is directly affected by soil and water quality, we estimated the cost function for the crop sector only. One problem with multi-output, multi-input cost functions is that, even for a few outputs and inputs, the number of parameters to be estimated is large (Ray 1982). However, the problem is less severe in our case because of the large number of data points available from combining time series and cross-sectional data. The problem is further reduced by estimating the cost function, and factor-and revenue-share equations simultaneously. One output (Divisia Index of all crop outputs) and six inputs (chemicals, water, labour, land, machinery, and animal/bullock costs) were included in the function. In the cost function, as in any other dual function, input prices rather than physical quantities were used.

The definition of the variables in the cost function are given in Table 5. The effect of technological change was proxied by the proportion of area sown to modern wheat varieties. Soil and water quality variables were as described above. The literacy rate was used as a proxy for labor quality engaged in crop production. Regional trend dummies were included in the function to capture the trend in regional resource quality due to factors not included in the function.

The cost function in equation (2) along with the factor- and revenue-share equations and restrictions[5] were simultaneously estimated using the seemingly unrelated regression (SUR) procedure. In view of the adding-up requirement of the input share, one equation (for draft animal costs) was deleted. Three models were separately estimated. Model 1 was estimated excluding soil and water quality parameters, and infrastructure related variables; in Model 2 only soil and water quality parameters were included; and in Model 3 both the soil and water quality and infrastructure related variables were included. The parameters in the factor-and revenue-share equations were restricted to the respective parameters in the cost equation, assuming profit-maximizing behavior.

The coefficients of the estimated cost functions are reported in Table 6. The variable on MVs of wheat, proxy for technological change had consistent sign and was highly significant in all the models. The total effect of MVs is in the range of 14.3% (Model 1) to 19.6% (Model 2). The effect of technological change is perhaps underestimated in this analysis as indirect effect say through improved cropping intensity, etc. is not captured in this analysis.

The sign of all the soil quality related parameters are as expected, and significant at the 5% level in Model 2. Organic matter and phosphorus have negative signs, while total soluble salts, an indication of salinity, has positive sign, confirming other studies that salinity is an important constraint in the crop production sector of Pakistan (Siddiq 1994). Of the two water quality related variables, only

Table 5. Variable definitions used in the translog cost function for irrigated agriculture of Pakistan's Punjab, 1971–94

Independent variables

q_1 = output = Crop output measured in divisia index number of production (1965=100)

w_1 = fertilizer = Divisia index of N, P, and K prices of nutrient and spray prices

w_2 = water = Index of tubewell water price

w_3 = labor = Index of wage rate of labor

w_4 = land = Divisia index of annual rent of irrigated and unirrigated land

w_5 = machine = Index of tractor prices

w_6 = animal = Index of feed, fodder, interest, and miscellaneous animal costs per standard animal unit

S_1 = soil organic matter = Index of organic matter content in the soils (average of all the observations in a district)

S_2 = soil phosphorus = Index of available phosphorus in the soils (average of all the observations in a district)

S_3 = salts in soil = Index of total soluble salts in the soils (average of all the observations in a district)

S_4 = electroconductivity = Index of electroconductivity of water (average of all the observations in a district)

I_1 = modern variety = Index of proportion of the total wheat area under modern wheat varieties

I_2 = cropping intensity = Index of cropping intensity defined as total cropped area divided by net sown area

L_1 = education = Index of percentage of farmers who can read and write

L_2 = road = Index of the inverse of the average distance of a village from a road

T = trend at the cropping system level = Regional time trend variable. Its value for a specific region was equal to trend (0,1,2,.....for 1965, 1966, 1967....), and zero otherwise

D = district dummy = Set of district dummy variables having a value of one for a district, and zero otherwise

Dependent variables

s_1 = fertilizer factor share = is (total cost of all types of fertilizer nutrients and spray cost)÷(total farm production expenditure)

s_2 = water factor share = (total cost of tubewell operating cost and canal water cost) ÷ (total farm production expenditure)

s_3 = labor factor share = (total cost of labor including family labor evaluated at the unskill wage rate) ÷ (total farm production expenditure)

s_4 = land factor share = (rent of irrigated and unirrigated land)÷ (total farm production expenditure)

s_5 = machine factor share = (total operating cost of tractor, harvester, threshing, and bullock)÷ (total farm production expenditure)

s_6 = animal factor share = (interest and miscellaneous animal cost) ÷ (total farm production expenditure)

y_1 = revenue share = (marketing revenue from all crops) ÷ (total farm production expenditure)

C = total cost = Index of farm production expenses (1965=100), which includes total chemicals, water, labor, land, machinery, and draft power.

Table 6. Estimated coefficient of the translog cost function for the crop sector of irrigated Pakistan's Punjab, 1971-93 (dependent variable = log of the index of total cost)

Variable	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Intercept	0.2780	0.0227	0.4304	0.1228	0.1763 ns	0.1363
Output	0.4286	0.0186	0.4336	0.0187	0.4328	0.0188
Output^2	0.0653	0.0139	0.0723	0.0140	0.0870	0.0142
Fertilizer	0.0010	0.0041	0.0016 ns	0.0041	0.0011 ns	0.0041
Water	0.1084	0.0040	0.1087	0.0040	0.1092	0.0040
Labor	0.4402	0.0079	0.4387	0.0080	0.4379	0.0079
Land	0.4458	0.0062	0.4460	0.0062	0.4470	0.0062
Machine	–0.0287	0.0046	–0.0283	0.0046	-0.0286	0.0046
Animal	0.0332	0.0029	0.0332	0.0029	0.0334	0.0029
Fertilizer * output	0.0350	0.0032	0.0357	0.0032	0.0372	0.0032
Water * output	0.0386	0.0031	0.0380	0.0031	0.0373	0.0031
Labor * output	–0.0688	0.0069	–0.0701	0.0069	–0.0720	0.0069
Land * output	–0.0306	0.0053	–0.0301	0.0053	–0.0299	0.0053
Machine * output	0.0330	0.0034	0.0336	0.0034	0.0346	0.0034
Animal * output	–0.0072	0.0018	–0.0071	0.0018	–0.0072	0.0018
Fertilizer^2	0.0291	0.0039	0.0291	0.0039	0.0288	0.0039
Water^2	0.0783	0.0057	0.0777	0.0057	0.0766	0.0057
Labor^2	0.1326	0.0089	0.1337	0.0089	0.1343	0.0089
Land^2	0.2639	0.0092	0.2640	0.0092	0.2644	0.0092
Machine^2	–0.1680	0.0081	–0.1678	0.0081	–0.1684	0.0081
Animal^2	0.3598	0.0376	0.0353	0.0379	0.3712	0.0388
Fertilizer * water	–0.0186	0.0036	–0.0184	0.0036	–0.0177	0.0036
Fertilizer * labor	0.0485	0.0037	0.0482	0.0037	0.0479	0.0037
Fertilizer * land	–0.0098	0.0041	–0.0097	0.0041	–0.0095	0.0041
Fertilizer * machine	–0.0408	0.0038	–0.0407	0.0038	–0.0411	0.0038
Fertilizer * animal	–0.1339	0.0244	–0.1251	0.0254	–0.1087	0.0262
Water * labor	–0.0281	0.0039	–0.0277	0.0039	–0.0272	0.0039
Water * land	–0.0619	0.0050	–0.0620	0.0050	–0.0625	0.0050
Water * machine	0.0440	0.0049	0.0440	0.0049	0.0446	0.0049
Water * animal	–0.2387	0.0265	–0.2220	0.0273	–0.2257	0.0277
Labor * land	–0.2109	0.0070	–0.2114	0.0070	–0.2119	0.0070
Labor * machine	0.1157	0.0041	0.1153	0.0041	0.1148	0.0041
Labor * animal	–0.1225	0.0421	–0.1358	0.0423	–0.1737	0.0434
Land * machine	0.021	0.0051	0.0212	0.0051	0.0218	0.0051

Continued

Table 6. Continued						
Variable	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Land * animal	–0.1731	0.0344	–0.1661	0.0345	–0.1591	0.0351
Machine * animal	0.1134	0.0547	0.1011	0.0550	0.1012	0.0552
$Land^2$	0.2639	0.0092	0.2640	0.0092	0.2644	0.0092
$Machine^2$	–0.1680	0.0081	–0.1678	0.0081	–0.1684	0.0081
$Animal^2$	0.3598	0.0376	0.0353	0.0379	0.3712	0.0388
Fertilizer * water	–0.0186	0.0036	–0.0184	0.0036	–0.0177	0.0036
Fertilizer * labor	0.0485	0.0037	0.0482	0.0037	0.0479	0.0037
Fertilizer * land	–0.0098	0.0041	–0.0097	0.0041	–0.0095	0.0041
Fertilizer * machine	–0.0408	0.0038	–0.0407	0.0038	–0.0411	0.0038
Fertilizer * animal	–0.1339	0.0244	–0.1251	0.0254	–0.1087	0.0262
Water * labor	–0.0281	0.0039	–0.0277	0.0039	–0.0272	0.0039
Water * land	–0.0619	0.0050	–0.0620	0.0050	–0.0625	0.0050
Water * machine	0.0440	0.0049	0.0440	0.0049	0.0446	0.0049
Water * animal	–0.2387	0.0265	–0.2220	0.0273	–0.2257	0.0277
Labor * land	–0.2109	0.0070	–0.2114	0.0070	–0.2119	0.0070
Labor * machine	0.1157	0.0041	0.1153	0.0041	0.1148	0.0041
Labor * animal	–0.1225	0.0421	–0.1358	0.0423	–0.1737	0.0434
Land * machine	0.021	0.0051	0.0212	0.0051	0.0218	0.0051
Land * animal	–0.1731	0.0344	–0.1661	0.0345	–0.1591	0.0351
Machine * animal	0.1134	0.0547	0.1011	0.0550	0.1012	0.0552
Proportion of modern variety area	–0.1460	0.1000	–0.1960	0.1010	–0.1430	0.1020
Organic matter content in soils (%)	–	–	–0.0562	0.0150	–0.0560	0.0149
Available phosphorus in soil (ppm)	–	–	–0.0224	0.0105	–0.0257	0.0106
Total soluble salts in soil (%)	–	–	0.0195	0.0051	0.0171	0.0051
Residual sodium carbonate (me/l)	–	–	0.0144	0.0021	0.0140	0.0020
Electroconductivity of tubewell water (mohl/c)	–	–	–0.0118 ns	0.0174	–0.0163 ns	0.0175
Education	–	–	–	–	–0.2529	0.0476
Distance from market	–	–	–	–	–0.1594	0.0276
Wheat-mixed	0.0060	0.0015	0.0070	0.0017	0.0016	0.0003
Wheat-cotton	–0.0039	0.0023	–0.0039	0.0024	0.0012	0.0004

Continued

Table 6. Concluded

Variable	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Wheat-rice	0.0074 [ns]	0.0019	0.0071	0.0020	0.0021	0.0003
Wheat-low intensity	0.0013	0.0017	0.0019	0.0019	0.0011	0.0002
Overall Punjab [a]	0.0024	0.0018	0.0022 [ns]	0.0020	0.0017	0.0003

a = To estimate this, the function was re-estimated by replacing the regional trend with an overall trend. The order coefficient of the function remained similar, thus not reported here.

All the coefficient are significant at least at the 10% level, except those bearing the ns sign.

Table 7. Region-specific productivity decline (% per annum) due to soil and water quality degradation in Pakistan's Punjab during 1971-94

	Residual carbonate	Available phosphorus	Available organic matter	Total soluble salts in water	Total effect
Wheat-mix	0.06	0.07	0.07	0.02	0.22
Wheat-rice	0.07	0.12	0.14	0.08	0.41
Wheat-cotton	0.02	0.11	0.11	0.05	0.30
Wheat-low intensity	0.05	0.10	0.13	0.00	0.29
Punjab	0.05	0.10	0.11	0.04	0.35

residual sodium carnbonate produced a consistent and significant coefficient.

The effect of soil and water quality degradation was evaluated at the system-specific rate of deterioration (Table 7). Together these changes in soil and water quality are estimated to have increased costs (reduced resource productivity) in the province by 7.7% over the study period at the rate of 0.35% per annum. The highest degradation was in wheat-rice system where productivity deteriorated at the rate of 0.41% per annum. The lowest deterioration was in wheat-mix and wheat-low intensity regions. The highest deterioration came from the depletion of organic matter and phosphorus in the soil.

In addition, resource quality is deteriorating not only due to these measured changes in soil and water quality, but also due to other factors not included in the function. This is shown by the positive and significant (at least at the 5% level) coefficients for time trends in all production systems, as well as for the whole province (0.173% per year), when the effect of improvement in human and physical infrastructure is controlled (Model 3). The highest trend increase in cost occurred in the rice-wheat region (0.21% per annum). Other factors, such as development of insect-pest complex due to inappropriate use of pesticides, depletion of water aquifers, and development of a hard plowpan due to tractorization may be responsible for this degradation (Byerlee 1992, Hobbs and Morris 1996). This measure of resource degradation is probably on the low side due to failure to account for some positive effects of technological change that may have been captured in the trend variables. Moreover, massive private and public sector investment to control the water-logging and salinity is not included in the cost function which relates to private costs and returns only.

Finally, the quality of human and physical resources plays a critical role in improving agriculture productivity, especially in a dynamic agriculture, like that of the irrigated Punjab. A 10% increase in the literacy rate is expected to increase crop sector productivity by 2.5% confirming other evidence of high returns to education in post-Green Revolution agriculture (Hussain and Byerlee 1996, Ali and Flinn 1989). Similarly, a 10% improvement in the distance of an average village from roads will enhance productivity by 11.6%.

Conclusions

Although results achieved in Pakistan with Green Revolution technologies are impressive, the results of this study raise important questions about the sustainability of those gains, especially in the light of growing evidence of degradation of land and water resources. In this study, the assembly and analysis of a very comprehensive data set on both crop and livestock production, as well as a number of soil and water quality variables provide a unique opportunity to understand some of the underlying trends in major production systems of Pakistan's irrigated Punjab.

On the surface, overall output growth in the sector of over 3% annually for nearly three decades, and TFP growth of 1.25% per year, suggest a fairly dynamic sector backed by significant technical change. However, growth in land productivity has slowed since the Green Revolution while labor productivity has jumped with acceleration of tractorization so that much of the recent growth in TFP is due to adoption of labor-saving technologies. A closer examination also shows considerable variation in productivity growth by production system. Crop TFP growth was relatively high in two production systems (wheat-cotton and wheat-mungbean), modest in one system (wheat-mixed), and negative in the wheat-rice system.

Even in those systems with high TFP growth, there is evidence of substantial resource degradation in soil and water quality throughout the province. The estimation of a cost function across districts and over time including several variables for resource quality and variables for technical change suggests that resource degradation had important negative effects on productivity in all systems, and especially in the wheat-rice system. Reduction in organic matter and available phosphorus in soils, increase in total soluble salts in soils, and an increase in residual sodium carbonate in tubewell water used for irrigation were the main variables affecting crop productivity. Other factors, such as development of insect-pest complexes, although not included in the analysis, are believed to be responsible for further reduction in resource productivity. Thus, TFP growth would have been much higher in the absence of resource degradation.

These results and the stagnation of output in recent years, combined with large imports of wheat, underline the urgency of developing a concerted approach to arresting resource degradation in Pakistan's most valuable asset – its irrigated land base. This will require strong public and private initiative on several fronts – increased investment in high quality crop and resource management research and extension, development of diversified cropping patterns and rotations, removal of price distortions on key inputs, especially water, and special incentives to invest in inputs such as gypsum that can counteract the problem of poor quality tubewell water. Finally, there is a need to enhance the pace of technological change, as part sources of productivity growth are being exhausted. This implies increased investment in new areas of science, especially biotechnology, to break the yield frontier.

End Notes

[1] The translog form is preferred because specific features of technology (like returns to scale or homotheticity) may be tested by examining the estimated model parameters. Specifically, if the technology is homothetic, the dual cost function is multiplicatively separable in output quantities and input prices. In the translog case, this requires that $g_{iz} = 0$ (for all i and z) so that the quadratic interaction terms between output levels and input prices should disappear. Similarly, the return to scale can be estimated, rather than imposed through the model. For other applications of the translog cost function see Berndt and Christensen (173); Christensen, Jorgenson, and Lau (1975), and Binswinger (1974).

[2] The translog (dual) cost function can be regarded as a quadratic approximation to the unspecified "true" cost function. [2*]In this context $b_{ij} = b_{ji}$ and $f_{zu} = f_{uz}$ for all i, j, u, and z. Any sensible cost function must be homogenous of degree 1 in input prices. In the translog function (1), this requires:

$$\sum_{z=1}^{n} e_z = 1, \quad \sum_{u=1}^{n} f_{uz} = 0 (z, u = 1,2,......,n) \text{ and } \sum_{i=1}^{m} g_{iz} = 0 (z = 1,2,......,n) \qquad (3)$$

Estimating the full dual system (i.e. cost and share equations together) leads to much higher efficiency. From the translog cost function and Shephard's lemma, we derive input share equations:

$$s_z = w_z x_z / C = e_z + f_{z1} \ln w_1 + ... + f_{zn} \ln w_n + g_{i1} \ln q_1 + ... + g_{im} \ln q_m \qquad (4)$$

where s_z are input share in the total cost as defined before. These shares must add up to l for all prices and outputs, such that

$$\sum_{z=1}^{n} e_z = 1, \quad \sum_{u=1}^{n} f_{uz} = 0, \text{ and } \sum_{i=1}^{m} g_{iz} = 0 \text{ (for } z = 1,2,......,n) \qquad (5)$$

Note that these are the same conditions implied by linear homogeneity of the cost function in input prices. If we additionally assume marginal cost pricing for the outputs, we obtain the relations:

$$y_i = \partial \ln c / \partial \ln q_i = (\partial C / \partial q_i) \cdot (q_i / C) = p_i q_i / C$$

for each out i. This leads to the "revenue share" equations as follows:[4]

$$y_i = a_i + b_{i1} \ln q_1 + ... + b_{im} \ln q_m + g_{i1} \ln w_1 + ... + g_{in} \ln w_n, \qquad (6)$$

where ($i = 1,..., m$)

[3]Depreciation cost was not included in livestock as appreciation of the younger stock was assumed to cancel the depreciation of older stock.

[4] Similar results have been observed in a recent study of the Indian Punjab (Murghai 1998).

[5] The translog (dual) cost function can be regarded as a quadratic approximation to the unspecified "true" cost function (see 2* above).

References

Ali, F., and **Parikh**, **A.** 1992. Relationship among labor, bullock, and tractor inputs in Pakistan's agriculture. Amer. J. Agr. Econ. 74 (May 1992): 371–377.

Ali, M. 1996. Quantifying the socio-economic determinants of sustainable crop production: an application to wheat cultivation in the Tarai of Nepal. Agr. Econ. 14(1996):45–60.

Ali, M. and **Flinn**, **J.C.** 1989. Profit efficiency among basmati rice producers in Pakistan Punjab. Amer. J. Agr. Econ. 71 (May 1989):303–310.

Ali, M. and **Velasco**, **L.E.** 1993. Intensification-induced resource degradation: the crop production sector in Pakistan. Draft paper. Manila, International Rice Research Institute.

Ali, M., Malik, I.A., Sabir, H.M. and **Ahmad**, **B.** 1997. The mungbean green revolution in Pakistan, Technical Bulletin No. 24, Asian Vegetable Research and Development Center, Tainan, Taiwan.

Alston, J.M., Anderson, J.R. and **Pardey**, **P.G.** 1995. Perceived productivity foregone, future farm fruitfulness and rural research rationalisation *in* Agricultural competitiveness, market forces and policy choices: proceedings of the XXII Conference of the International Agricultural Economics Association, (Headley, D. and Peters, G.H., eds.). Gower, Aldershot.

Antle, J. H., and **Capalbo**, **S.M.** 1988. An introduction to recent development in production theory and productivity measurement, *in:* Agricultural productivity: measurement and explanation. (Capalbo, S.M. and Antle, J.M., eds.). Washington, DC. Resource for the Future.

Azam, Q.T., Bloom E.A. and **Evenson**, **R.E.** 1991. Agricultural research productivity in Pakistan, Islamabad. Pakistan Agricultural Research Council and New Haven, Yale University.

Binswanger, H.P. 1974. A cost function approach to the measurement of factor demand and elasticities of substitution. Amer. J. Agr. Econ. 56(1974):377–86

Byerlee, D. 1992. Technical change, productivity, and sustainability in irrigated cropping systems of South Asia: emerging issues in the post-green revolution era. Journal of International Development 4(5):477–496.

Byerlee, D., Akhtar, M.R., and **Hobbs**, **P.R.** 1987. Reconciling conflicts in sequential cropping pattern through plant breeding: the example of cotton-wheat in Pakistan's Punjab. Agr. Sys. 24(1987):291–304.

Cassman, K.G., and **Pingali**, **P.L.** 1995. Extrapolating trends from long-term experiments to farmers' fields: the case of irrigated rice systems in Asia, *in:* Agricultural sustainability in economic, environmental, and statistical terms, (Barnett, V., Payne, R. and Steiner, R., eds.). London, John Wiley and Sons Ltd.

Christensen, R., Jorgenson, D.W. and **Lau**, **L.R.** 1975. Transcendental logarithmic utility functions. Amer. Econ. Rev. 65(1975):367–383.

Diewert, W.E. 1976 Ëxact and superlative index number. J. Econometrics 4(1976):115–45.

Ehui, S.K., and **Spencer**, **D.S.C.** 1993. Measuring the sustainability and economic viability of tropical farming systems: A model from Sub-Saharan Africa. Agr. Econ. 9(1993):279–296.

Faeth, P. 1993. Agricultural policy and sustainability: case studies for India, Chile, the Philippines and the United States, World Resource Institute, Washington, DC.

Faruqee, R. 1995. Government's role in Pakistan agriculture: major reforms are needed. Policy Research Working Paper No. 1468, Washington, World Bank.

Flinn, J.C., and **De Datta**, **S.K.** 1984. Trends in irrigated rice yields under intensive cropping at Philippine Research Stations. Field Crop Research. 9(1)(1984):1–15.

Fujisaka, S. Rice-wheat in South Asia: system and long-term priorities established through diagnostic research, Agr. Systems (in press).

Hobbs, P., and **Morris**, **M.L.** 1996. Meeting South Asia's future food requirements from rice-wheat cropping systems: priority issues facing researchers in the post-green revolution era. Natural Resources Group Paper 96–01. Mexico, D.F., International Maize and Wheat Improvement Center (CIMMYT).

Hussain, S.S., and **Byerlee**, **D.** 1995. Education and farm productivity in post-green revolution Asia, *in:* Agricultural competitiveness: market forces and policy choice. (Peters, G.H. and Hedley, D., eds.), proceedings of the Twenty-Second International Conference of Agricultural Economists, 22–29 August, 1994. Harare, Zimbabwe, Aldershot, UK, Dartmouth.

Khan, M.H. 1994. The structural adjustment process and agricultural change in Pakistan in the 1980s and 1990s, draft paper, Simon Fraser University, Vancouver.

Lynam, J.K., and **Herdt**, **R.W.** 1989. Sense and sustainability: sustainability as an objective in international agricultural research. Agr. Econ. 3(1989):381–398.

Murghai, R. 1996. Diversity in agricultural growth and technical change: a district-wise analysis of the Punjab and Haryana growth experience, draft paper. Washington, DC. World Bank.

Pingali, P.L., Hossain, M. and **Gerpacio**, **R.V.** 1997. Asian rice bowls: the returning crisis? Wallingford, CABI in association with IRRI, Los Banos.

Ray, S.C. 1982. A translog cost function analysis of U.S. agriculture. 1939-77. Amer. J. Agr. Econ. 64(November 1982):490–498.

Rosegrant, M.W. and **Evenson**, **R.E.** 1992. Agricultural productivity and sources of growth in South Asia. Amer. J. Agri. Econ., 74(3): 757–761.

Sharif M., Longmire, J., Shafique, M. and **Ahmed, Z.** 1992. Adoption of basmati 385: implications for time conflicts in rice-wheat system of Pakistan's Punjab. *in:* Farming systems of Pakistan. (Byerlee, D. and Hussain, T., eds.). Lahore, Vanguard Publishers.

Siddiq, A. 1994. Sustainability of the Indus basin: impact of tertiary salinity/sodicity on wheat productivity, damage assessment and future public policy. Ph.D. Dissertation, Dept. of Agricultural Economics, University of Illinois, Urbana-Champaign.

Squires, D.E. 1991. Productivity measurement in common property resource industries: an application to the specific coast trawl fisheries, National Marine Fisheries Service, South Fisheries Service Centre, La Jolla, CA.

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