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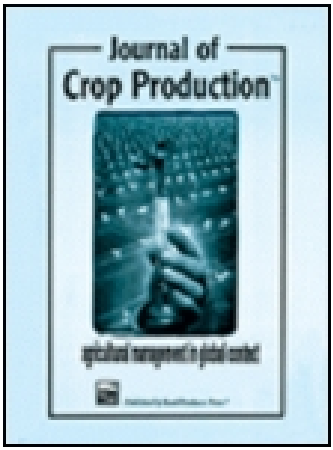

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The Rice-Wheat Cropping System of South Asia

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The Rice-Wheat Cropping System of South Asia: Trends, Constraints and Productivity– A Prologue

P. K. Kataki
P. Hobbs
B. Adhikary

SUMMARY. The rice-wheat cropping pattern of South Asia has seen a phenomenal growth in area, production and yield in the last two decades. This cropping system encompasses the four countries of Bangladesh, India, Nepal and Pakistan along the Indo-Gangetic Plains (IGP) and into the mid-hills of the Himalayas. Traditionally, wheat was grown mostly in the northwestern belt and rice in the eastern belt of the IGP. With the introduction of improved high yielding, input responsive, short duration rice and wheat varieties, the rice-wheat pattern became feasible and saw both crops grown in the same year. In this pattern, rice is grown during the summer months followed by wheat in the winter months. It is now found as a major system throughout the IGP. However, there are signs that the productivity of this cropping system is either stagnating or declining. Several site-specific benchmark and diagnostic farm level surveys have been conducted in the region to understand the

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constraints of this cropping system and ways to improve its productivity and sustainability. This article analyzes the trend in the area, production and yields of rice and wheat as a whole and assumes these trends are similar in rice-wheat areas. It also summarizes the results of the farm level surveys and productivity analyses done in the IGP on rice and wheat. *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-342-9678. E-mail address: <getinfo@haworthpressinc.com> Website: <http://www.HaworthPress.com> © 2001 by The Haworth Press, Inc. All rights reserved.]*

KEYWORDS. Bangladesh, cropping pattern, cropping system, Himalayas, India, Indo-Gangetic Plains, Nepal, Pakistan, productivity, rice, South Asia, wheat

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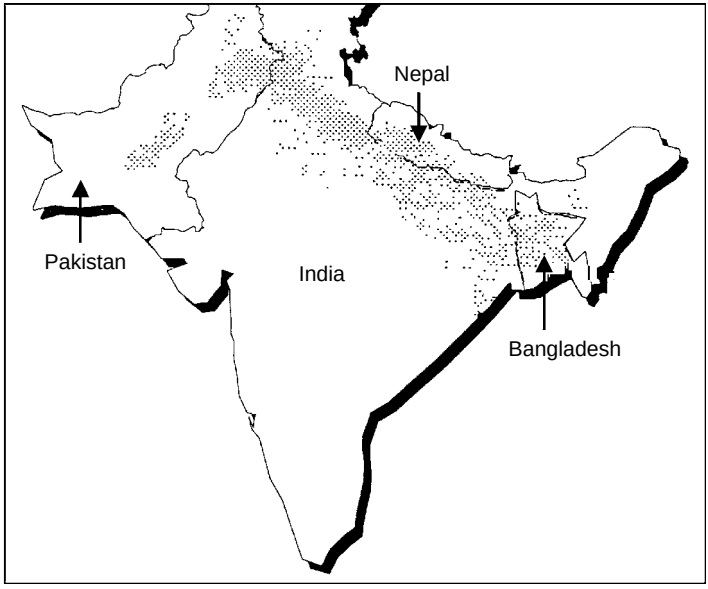
INTRODUCTION

The ''rice-wheat cropping system'' (RWCS) region of South Asia spans the fertile Indo-Gangetic Plains (IGP) of four countries, from western Pakistan, northern, northwestern and eastern India, the Terai plains and portions of the Himalayan mid-hills of Nepal, to the western and northwestern region of Bangladesh (Figure 1). Traditionally, eastern India, Nepal and Bangladesh were rice-growing areas with very little wheat being cultivated, while in northwestern India and Pakistan, wheat was the major cereal crop with very little or no rice being grown in the early 1960's. The traditional varieties of rice and wheat were of longer duration; thereby requiring more time to reach physiological maturity for harvest, and were not responsive to intensive inputs and management. The green revolution introduced shorter duration, dwarf, largely photo-insensitive, high yielding, and fertilizer responsive varieties of rice and wheat during the 1960's and 1970's. Due to these varietal changes, it was possible to grow rice during the monsoon months following wheat in the otherwise non-rice growing northwestern region of these fertile plains. Simultaneously, it was also possible to plant wheat in November/December after rice harvest in the eastern region of the IGP. During the last two decades, the spread of this cropping system in this fertile region earned it the terminology ''The Rice-Wheat Cropping System'' region.

Over twenty cropping patterns are practiced in South Asia, but the rice-wheat cropping sequence dominates in area, production and productivity (Yadav, Prasad and Singh, 1998). Besides appropriate vari-

FIGURE 1. Schematic map of the Indo-Gangetic Plains (IGP) showing the rice-wheat growing regions (shaded areas) of Bangladesh, India, Nepal and Pakistan.



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etal development, a key to the success of the rice-wheat rotation has been the development of irrigation facilities in the hotter and drier western region of the IGP. Regions with assured irrigation has favored the rice-wheat cropping system, while the rainfed and dryland regions support a larger variety of cropping patterns in addition to rice-wheat, due to the greater risks involved (Yadav, Gangwar and Prasad, 1998; Yadav, Prasad, Gangwar, 1998).

This article analyzes the trend in the area, production, and productivity of rice and wheat in the region, followed by a summary of the site-specific farm level surveys conducted in the region that identified the constraints in this cropping system. Finally, productivity analysis done on rice-wheat is discussed in the last section of this article. The data for the analysis of the acreage, production, and yield trends for this paper has been taken from country and international publications (multiple years) including the Fertilizer Association of India, Ministry of Agriculture, Nepal, Ministry of Agriculture, Pakistan, Bangladesh Bureau of Statistics, International Rice Research Institute, and FAO.

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Statistical Issues

Unfortunately, production and yield statistics are not collected on a cropping system basis, but rather for individual crops of rice and wheat, and so specific data solely for the rice-wheat cropping system is not available. This would require aggregating District level data and making assumptions for each District on what percentage of each crop is in the rice-wheat system. That was not feasible and so the following data is based on statistics for the entire region and includes data from all cropping systems. It is estimated that there are 12 million hectares of rice-wheat in the region, 9 million in India, 1.5 million in Pakistan and the rest in Nepal and Bangladesh. In Nepal and Bangladesh 80-85% of the wheat follows rice, so wheat statistics should follow total statistics. However, only 30% and 5% of the rice in Nepal and Bangladesh is in the rice-wheat system. In India, only 21% of the rice area and 35% of wheat is rice-wheat, so some caution should be given to interpreting the following trends. In Pakistan, 18% and 70% of the wheat and rice, respectively, are in the rice-wheat areas. The assumption is made that growth rates in area, production and yield for those in rice-wheat systems mimic rice and wheat in the whole country.

AREA, PRODUCTION AND YIELD TRENDS OF THE RICE-WHEAT CROPPING SYSTEM IN THE INDO-GANGETIC PLAINS

Area Trend: Rice

The acreage under rice has been steadily increasing in South Asia from 1958 to 1997. The increase in rice area growth in South Asia has been linear at 0.64% per annum rising from 43 million to more than 58 million hectares in 1998 (Figure 2A). The total rice acreage is highest for India, followed by Bangladesh, Pakistan and Nepal. Total acreage under rice increased from 33 million to over 43 million hectares in India at 0.6% per annum growth between 1958 and 1998 (Figure 2B). In Bangladesh, acreage under rice increased rapidly between 1958 and 1970 from 8 million hectares to over 10 million hectares at 1.9% per annum growth (Figure 2D). But between 1970 and 1997, the increase in the acreage growth under rice has slowed to 0.24% and was around 10.5 million hectares in 1997. The rice area growth increase in Paki-

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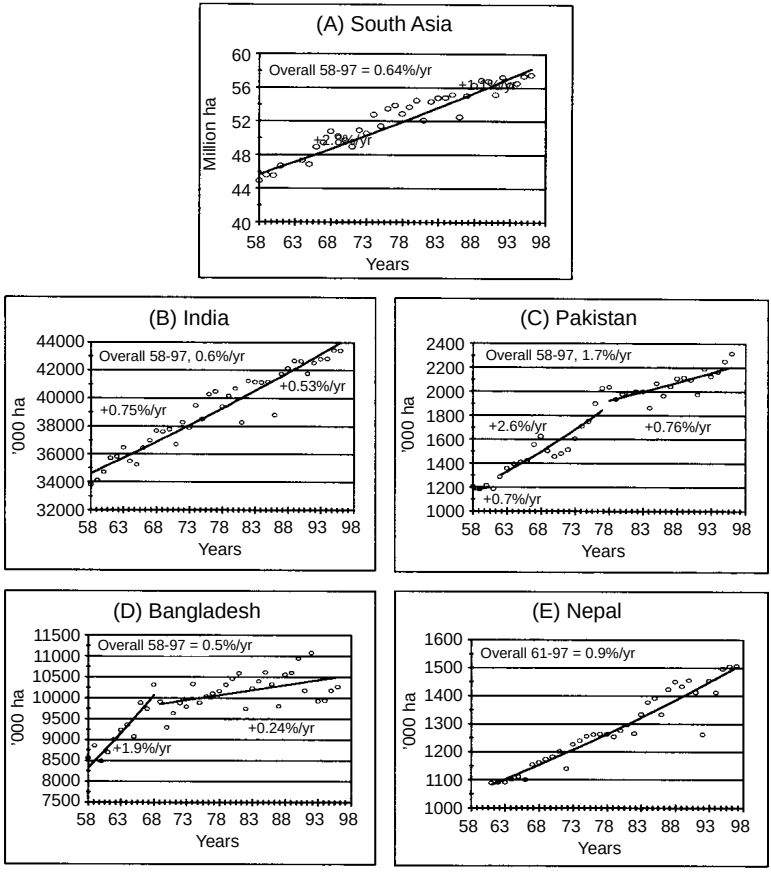
FIGURE 2. Rice area trends in South Asia, 1958-98.



stan was initially slow at 0.7% per annum, thereafter increasing rapidly from 1.2 million hectares in 1963 to two million hectares in 1979 at 2.6% annual growth rate. After 1979, the growth in the acreage of rice in Pakistan slowed to a rate of 0.76% per annum (Figure 2C). The total acreage under rice in Pakistan during 1997 was approximately 2.3 million hectares. Overall, the percent annual area growth increase for rice in Pakistan between 1958 to 1997 was 1.7% per annum. The growth in area under rice in Nepal started later in 1961, but this increase has been linear at 0.9% per annum ever since (Figure 2E).

Rice acreage in Nepal increased from 1.1 million hectares in 1961 to above 1.5 million hectares in 1997.

Area Trend: Wheat

Unlike the linear growth increase in area for rice in South Asia, the increase in the acreage of wheat has followed a sigmoid pattern (Figure 3A). Between 1958 and 1967, before the introduction of new varieties, wheat acreage growth for all of South Asia was as low as 0.6% per annum and grew from 17 million to about 18 million hectares in this period. Subsequent increase in wheat acreage growth was rapid at 2.8% per annum and area grew from 20 to more than 32 million hectares between 1967 and 1982. After 1982 area growth of wheat has slowed to 1.1%. Wheat acreage is highest for India, followed by Pakistan, Bangladesh and Nepal. The increase in the wheat acreage in India has followed a sigmoid pattern. Initial growth between 1958 and 1966 was slow at 0.1% annually with 13 million hectares in 1966 (Figure 3B). Between 1966 and 1983, wheat acreage growth rate in India increased at 3% per annum to reach 25 million hectares, after which the growth rate slowed to 1% a year to reach 26 million hectares in 1997. The overall growth rate in India during the period of Green Revolution (1967-1997) was 2%. The wheat acreage growth trend in Pakistan was linear since 1958 at 1.5% per annum (Figure 3C). The acreage rose from a little over 4.5 million hectares in 1958 to around 8.5 million hectares in 1997.

Wheat acreage growth rate in Bangladesh was initially at 3% per annum between 1968 and 1977, then rose to 4% per annum to reach 0.85 million hectares in 1997 (Figure 3D). Overall increase in wheat acreage in Bangladesh was a phenomenal 7.3% per year mainly due to a rapid increase from 1977-1980. Wheat acreage growth rate in Nepal followed a three-step process (Figure 3E). Initial growth rate was stagnant at –0.1% from 1961 to 1966 at 0.1 million hectares. From 1966 to 1986, the growth rate accelerated to 5.8% per annum to reach 0.6 million hectares. Thereafter, the wheat acreage growth rate slowed to 1.3% per annum to reach 0.65 million hectares in 1997. The overall growth rate in Nepal from 1966 to 1993 was an impressive 5.3% per annum.

Area increase under rice and wheat for the entire IGP is slowing as most land becomes double or triple cropped and more land goes for housing, industry, and other purposes. That means that future growth

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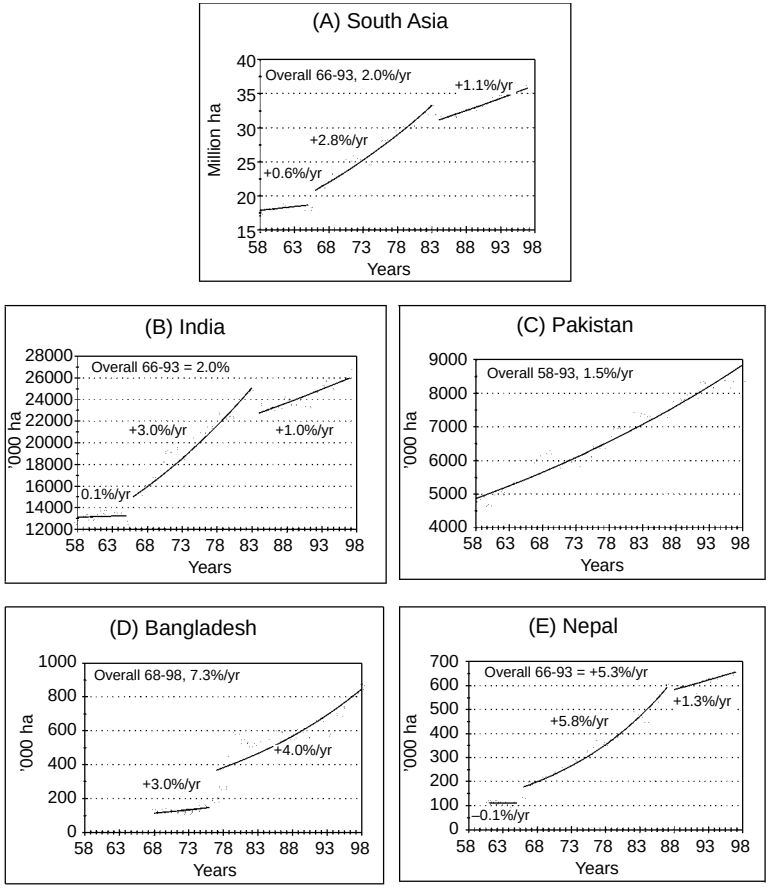
FIGURE 3. Wheat area trends in South Asia, 1958-98.



in production will have to come from increase in yield growth rates using technology that ensures sustainable growth and minimal damage to the resource base. Land will become more limiting and growth rates may even become negative.

Production Trend: Rice

Total rice production in South Asia has increased from 60 million tons in 1958 to 160 million tons in 1997 at an impressive growth rate of 2.5% per annum (Figure 4A). Total production has been the highest

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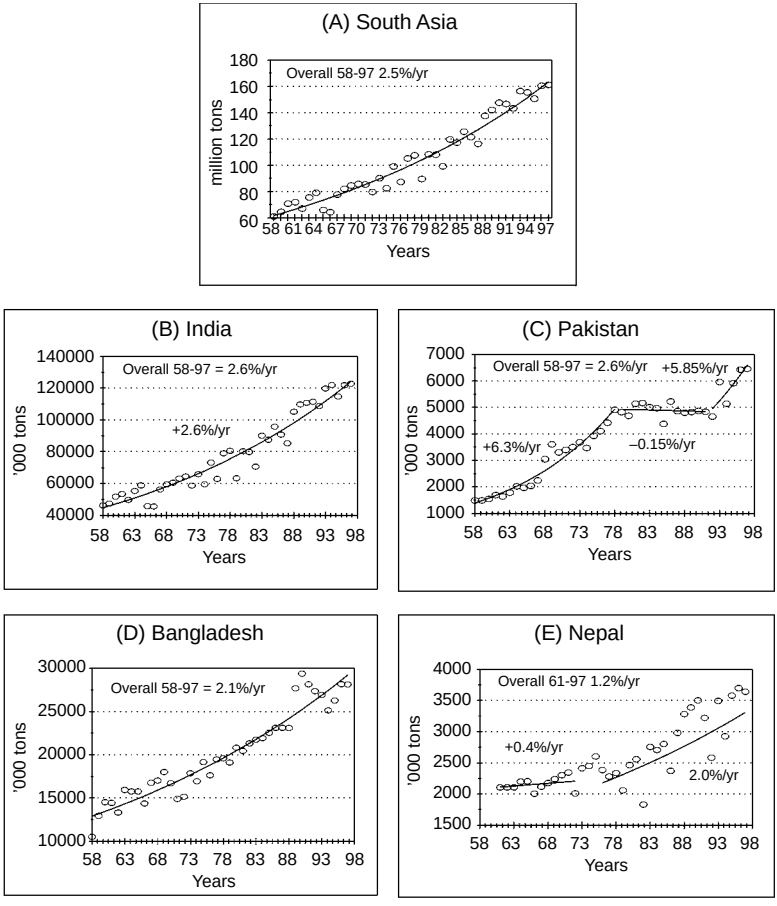
for India, followed by Bangladesh, Pakistan and Nepal. The production growth rate in India for rice has been generally linear between 1958 and 1997 at 2.6% per annum (Figure 4B). Total production in India was approximately 45 million tons in 1958, which increased to 120 million tons in 1997. The rice production growth trend in Bangladesh has been linear, similar to that of India's at 2.1% per annum (Figure 4D). Production in Bangladesh increased from 10 million tons in 1958 to around 30 million tons in 1997.

The production growth rate in Pakistan has seen a sigmoid growth

FIGURE 4. Rice production trends in South Asia, 1958-98.



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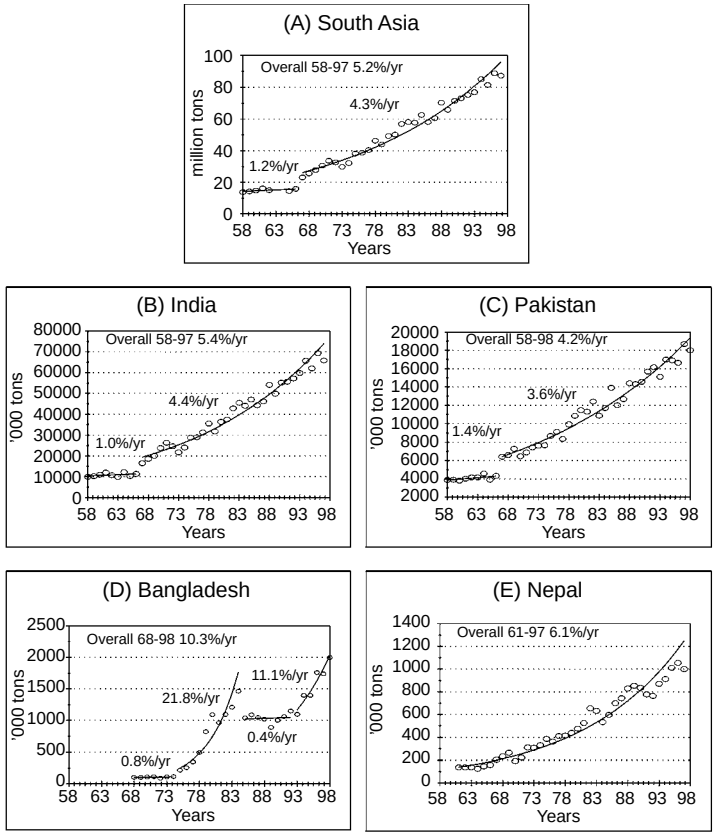
pattern–a growth rate of 6.3% from 1 million tons in 1958 to 5 million tons in 1979 due to the cultivation of modern high yielding varieties (Figure 4C). This impressive initial growth rate slowed to zero between 1979 and 1991 with production staying at 5 million tons, and then grew as production rose to 6.5 million tons between 1991 and 1997 at a growth rate of 5.8% per annum. The stagnant growth rate of rice production between 1979 to 1991 in Pakistan was largely due to cultivation with basmati rice, a traditional long duration, low yielding rice preferred for its aroma and flavor and for export. The overall production growth rate for Pakistan from 1958 to 1997 was 2% per annum. The rate of rice production growth increase started later in Nepal at an initial rate of 0.4% per annum between 1961 and 1973, after which the production growth increased at 2% per annum to reach 3.6 million tons in 1997 due to the introduction and spread of modern high yielding varieties (Figure 4E).

Production Trend: Wheat

The wheat production growth rate in South Asia was very rapid at 4.3% between 1967 and 1997 after an initial slow growth rate of 1% per annum from 1958 and 1967 (Figure 5A). For South Asia, the overall production growth rate since 1958 was an impressive 5.2% per annum for registering 90 million tons of wheat production in 1997. Wheat production has been the highest for India, followed by Pakistan, Bangladesh and Nepal. The overall wheat production in India registered a growth rate of 5.4% after an initial slow growth of 1% per annum between 1958 and 1967, followed by a rapid growth of 4.4% between 1967 and 1997 (Figure 5B). The total production in India reached 70 million tons in 1997. The overall wheat production in Pakistan was 4.2%, the increase being slow between 1958 and 1966 at 1.4%, thereafter increasing rapidly at 3.6% per annum between 1966 and 1998 (Figure 5C). Total wheat production in Pakistan reached 18 million tons in 1997.

Production growth rate increased in Nepal at a phenomenal 6.1% per annum from slightly over 0.1 million tons in 1961 to more than 1 million tons in 1997 (Figure 5E). In Bangladesh, wheat production trend was slow at 0.8% between 1968 and 1974, being stagnant at around 0.1 million tons (Figure 5D). Thereafter, production increased at 21.8% between 1974 and 1983 to register more than 1.2 million tons of wheat. From 1983 to 1992, wheat production in Bangladesh

FIGURE 5. Wheat production trends in South Asia, 1958-98.



stagnated with only 0.4% growth rate, but, after 1992, wheat production increased again at 11.1% per annum to reach around 2 million tons. The overall wheat production growth rate for Bangladesh was 10.35% per annum. The slack in the production growth in Bangladesh between 1983 and 1992 was largely due to the popularity of growing ''Boro'' or winter rice, which coincided with the wheat-growing season. Cultivation of ''Boro'' rice was possible due to development of its new varieties, and the popularity of shallow tubewell installations, which allowed winter rice to be grown in a dry season through assured irrigation. After 1992, the wheat production in Bangladesh increased again for several reasons. First, ''Boro'' rice required too much water

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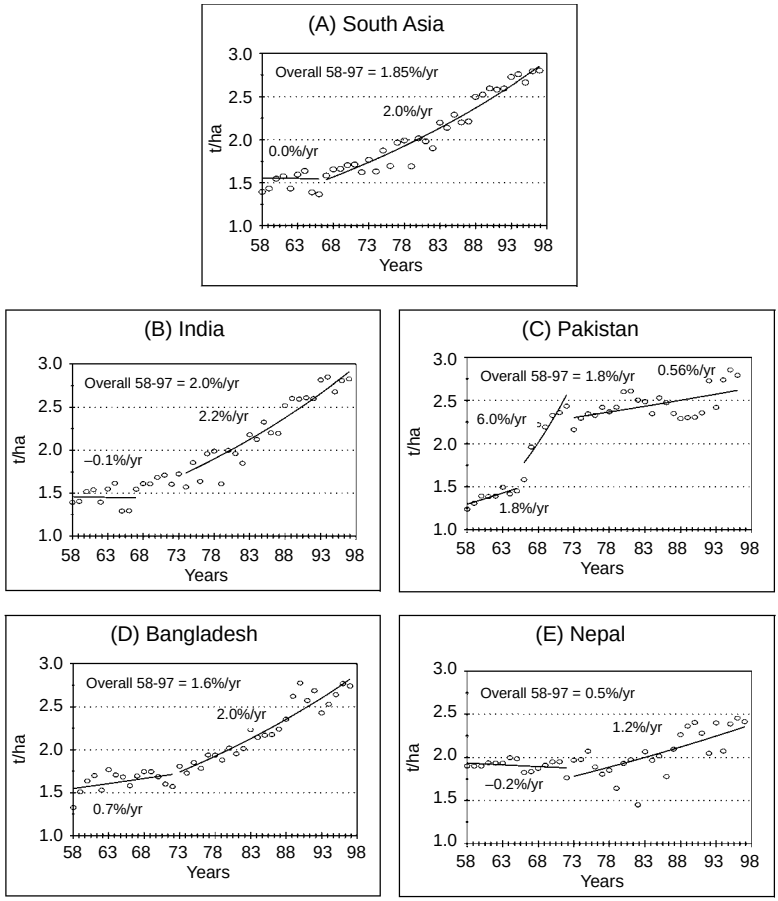
on coarser soils, where wheat is preferred. Second, the introduction of two-wheeled Chinese tractors made it easier to prepare land for wheat and allowed timelier planting and better yields.

Yield Trend: Rice

Overall yield growth rate for rice in South Asia was 1.85% per annum between 1958 and 1997 (Figure 6A). This includes the stagnant period from 1958 to 1967, after which yield growth rate regis-

FIGURE 6. Rice yield trends in South Asia, 1958-98.



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tered an increase of 2% per annum. Mean rice yield of 2.8 tons per hectare in 1997 was double that of the mean rice yields of 1958. The overall yield growth rate in Pakistan for rice was 1.8% per annum (Figure 6C). This increase was characterized by a gradual growth of 1.8% between 1958 and 1967, followed by a very rapid growth between 1967 to 1973 of 6%, decreasing thereafter to 0.56% per annum between 1973 and 1997 as more land was grown to low yielding *Basmati* rice varieties. After an initial stagnating rice yield growth rate between 1958 and 1967 in India, yield increased at 2.2% per annum to reach around 2.8 tons per hectare in 1997 (Figure 6B). Though scented or basmati rice is grown in selected districts of India, its acreage compared to non-scented high yielding modern varieties is only a fraction. Therefore, overall yield growth rate for India has been almost linear at 2% per annum.

The rate of rice yield growth in Nepal hasn't been consistent. The overall growth rate has been 0.5% between 1958 and 1997; this was due to a decline in rice yield from 1958 to 1973, followed by an increase in yield at 1.2% per annum from 1973 and 1997 (Figure 6E). The fluctuating yield trend for this water-loving rice crop in Nepal is a reflection of the yearly variation in the onset and duration of monsoon rains, as assured irrigation sources in Nepal is not as widespread as in the neighboring countries. In Bangladesh, the rate of rice yield increase has been a steady 1.6% per annum (Figure 6D). The initial years saw an increase of only 0.7% between 1958 and 1973, followed by a rapid increase of 2% per annum between 1973 and 1997 to a level of 2.8 tons per hectare. The latter rapid increase in rice yield can be attributed to an rapid increase in Boro rice during this period.

Yield Trend: Wheat

The overall wheat yield growth rate in South Asia has been 3.2% per annum between 1958 and 1997 (Figure 7A). This includes a slower growth of 0.8% between 1958 and 1967 followed by a more rapid 2.8% annual yield growth rate between 1967 and 1997. The average wheat yield in South Asia was around 2.5 tons per hectare in 1997. After a stagnant yield growth rate between 1958 and 1967, wheat yield increased at 2.3% in Pakistan from 0.8 tons in 1967 to 2.2 tons per hectare in 1997 (Figure 7C). Wheat yield increased from 0.8 tons per hectare in 1958 to 2.8 tons per hectare in 1997 in India (Figure 7B). The overall wheat yield growth rate in India was 3.3% per annum.

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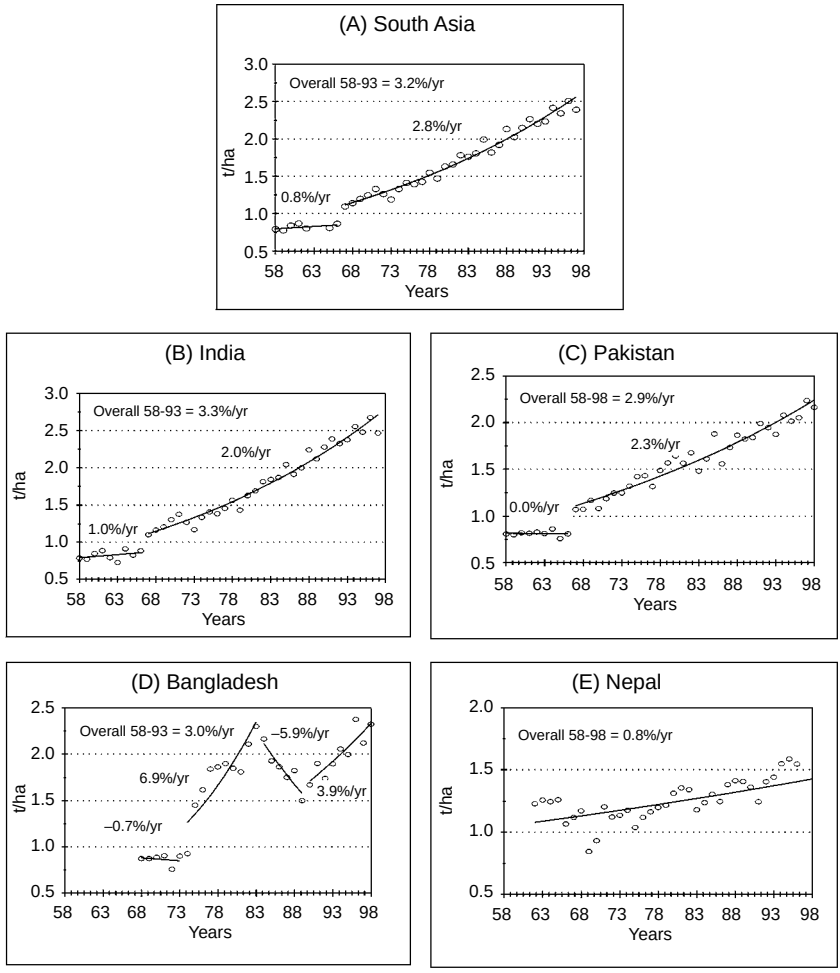
FIGURE 7. Wheat yield trends in South Asia, 1958-98.



Initially, from 1958 to 1967, yield growth rate increase was slow at 1% per annum, but increased rapidly to 3% per annum between 1967 and 1997 in India.

Wheat yield growth increase in Nepal fluctuated over the years. The overall wheat yield increase in Nepal has been 0.8% per annum from 1962 to 1998 (Figure 7E). The average yield in Nepal was around 1.6 tons per hectare in 1998. The yearly fluctuations in wheat yield for

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Nepal is a reflection of late planting of wheat over large areas especially for years registering low yields. Despite an overall yield increase of 3% per annum in Bangladesh between 1958 and 1993, the trend during these years has been very inconsistent (Figure 7D). Yield growth rate was stagnant during 1968 and 1974, increased rapidly between 1974 and 1983 at 6.9% per annum, and then declined almost at a similar rate of – 5.9% between 1983 and 1992.

Unlike the rest of the IGP, total area under irrigated rice in Bangladesh increased 100% between 1980 and 1990 due to the popularity of shallow tube wells. As a result of this single factor and the availability of newer varieties, acreage under winter ''Boro'' rice during the post-monsoon winter season increased by 87% and spring ''Aus'' rice by 51% during this period. These changes in the rice production scenario in Bangladesh brought about stagnation in the production and yield of wheat between 1980 and 1990 since ''Boro'' rice competed with wheat for land (Bhuiyan et al., 1993; Razzaque, Badaruddin and Meissner, 1995). But between 1992 and 1997, the wheat yield increased at 3.9% per annum to around 2.3 tons per hectare in 1997. This post 1992 surge in wheat production and yield of wheat in Bangladesh was probably due to falling prices of rice, and more cost of production, specially irrigation, of Boro rice. It was also helped by introduction of two-wheel Chinese tractors that allowed timelier and easier wheat planting and higher yields. Thus areas with coarser soils and poor water retention capacity, which were being cultivated under Boro rice, were reverted to wheat cultivation (Bhuiyan et al., 1993).

REGIONAL DIAGNOSTIC AND BENCHMARK SURVEYS: CONSTRAINTS OF THE RICE-WHEAT CROPPING SYSTEM

''Sustainability'' as a research objective is well recognized but its appropriate quantitative measurements is not well defined given the vast array in which it can be characterized and assessed (Harrington et al., 1992). The total production of rice and wheat in the Indo-Gangetic region has increased steadily in the last two decades. Under this scenario, it is often difficult to produce evidence of stagnating or declining productivity of the rice-wheat cropping system in the farmer's field. For this article, we define production as the total quantity of crop produce of economic value and productivity as the quantity produced per unit factor of interest. The unit factor of interest could be unit land

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area (e.g., yield), or any input. Other factors are also important to be considered but it is more difficult to document with sufficient accuracy the usage of these factors and its quantities in farmer's field, since farmers rely on memory, estimation, and experience rather than well-maintained records in South Asia.

Monitoring agronomic efficiency on a long-term basis within and between farmer's field and agro-climatic zones require a lot of resources and long-term commitment is essential. The quality and recommended quantity of crop inputs, the ease of access to these inputs, crop management and post-harvest storage and processing, economic condition of a farm household, market access and incentives, and prevailing weather conditions form a network of intertwined factors that determine agronomic efficiency. However, a regional effort between the national Institutes of the host countries of the IGP and the International agricultural centers has been to answer the question–Is the productivity of the rice-wheat cropping system stagnating or declining? Answering in the affirmative should be followed by an effort in understanding the underlying cause of yield stagnation or decline and searching for remedial solutions. As per the evidence provided in the subsequent articles, it is clear that within the IGP, solutions towards future yield growth will be eco-regional and site specific.

Three forms of simultaneous activities have been on going to collect evidence from farmer's field for possible rice and wheat yield stagnation or decline in the IGP. They include farmer's field diagnostic and benchmark survey, location specific long-term monitoring (8 to 9 years) surveys and research station managed long-term soil fertility experiments. This section discusses diagnostic and benchmark surveys. Data compilation from long-term monitoring surveys is not complete, and long-term soil fertility experiments suggests that there is evidence for rice and wheat yield decline.

Farmers field diagnostic and long-term monitoring surveys in rice-wheat growing areas of the region were proposed as one way to measure the sustainability and productivity of the rice-wheat cropping system of the IGP (Harrington et al., 1992; Harrington et al., 1993a). In the last decade, several one-time diagnostic and benchmark surveys have been conducted in the Indo-Gangetic region, collecting either qualitative, semi-quantitative or a combination of both forms of data. Since the diagnostic surveys were conducted in different locations, years and crop seasons, and at one time only, it is difficult to combine

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information from these surveys to analyze multi-locational trends of rice-wheat in farmer's field over time. However, these surveys are a major source of information about the constraints and practices of rice-wheat as it exists in the farmer's field and is therefore very valuable.

This section summarizes information (Table 1) from 15 diagnostic surveys (Ahmed et al., 1993; Baksh and Razzaque, 1999; Byerlee et al., 1984; Fujisaka et al., 1994; Gami et al., 1997; Harrington et al., 1993a; Harrington et al., 1993b; Harrington et al., 1993c; Hobbs et al., 1990; Hobbs et al., 1992; Meisner, 1992; Meisner, 1996; Saunders, 1990; Saunders, 1991; and Singh et al., 1996), and three benchmark surveys (Adhikari et al., 1999; Dhiman et al., 1999; and Hobbs et al., 1996) conducted in this region on rice-wheat in the last 10 years. Multidisciplinary teams of scientists conducted the diagnostic surveys using informal and semi-formal rapid rural appraisal approaches. The surveys lasted from 1 to 2 weeks and featured informal but structured

TABLE 1. List of problems for rice-wheat cropping systems in the Indo-Gangetic Plains based on 15 diagnostic surveys.

Wheat
• Late planting
• Inadequate plant stand
• Weed problems, especially grassy weeds
• Early season waterlogging
• Nutrient deficiencies, both macro- and micro-nutrients
• Late season moisture stress and water management
• Various leaf diseases
• Varietal problems
Rice
• Pests and disease
• Mid-season and late season water stress and water management
• Nutrient deficiencies
• Weeds for direct seeded rice

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farmer interviews and covered farmers' practices and knowledge on land types, cropping systems and crops, management, production, field observations and problem identification. Teams met in the afternoon to discuss findings and develop problem and cause diagrams before planning the next day's activity. Most problems were identified by farmers and researchers and prioritized using simple scoring methods. Opportunities for research and extension interventions were identified. A systems rather than a single commodity analysis was done. The three-benchmark surveys were conducted at sites that were chosen for longer term monitoring farmer practices. These surveys provide a detailed description of farms and farmer practices in selected rice-wheat fields.

Characteristics of the Rice-Wheat System

Rice is grown in the Indo-Gangetic Plains in areas with as little as 120 mm rain to areas with more than 1800 mm. Rice is grown in some areas with full irrigation and others with supplemental or just as a rainfed crop. The same is the case for wheat although in the rice-wheat system the majority of fields of wheat get at least one initial irrigation. Drought is therefore an issue in the rice-wheat system where lack of rain can affect the start on the rice season and the yield of the subsequent crops. This can lead to delays in rice planting, but where irrigation is available rice planting can start as early as May (Punjab, India).

Soils and hydrological situations differ throughout the IGP. On the lower terraces with heavier, poorly drained soils wheat is less suited whereas on higher terraces with coarser soils and good drainage, rice is less suitable. In the Eastern IGP two or three rice crops may be grown instead of rice-wheat on the lower terraces. Wheat is then found on higher terraces where there is better drainage and better soils. On coarser textured soils in the Western IGP rice is grown with irrigation and wheat follows rice.

In the rice-wheat systems, rice and wheat are not the only crops grown. Rotations include many substitute crops for wheat in the winter season including oilseeds (brassica, flax, sunflower, etc.), pulses (gram and lentil) and fodders (berseem clover, maize, etc.). In some rainfed areas mixtures of oilseeds and legumes are grown with wheat and in some irrigated areas brassica is commonly mixed with wheat. In some areas, sugarcane is grown in rotation with rice and wheat.

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Otherwise there are not many alternatives for rice in the wet monsoon period, except some fodder crops, although in Bangladesh jute can substitute for rice. In the western reaches of the IGP only one crop of rice and one of wheat is possible in a year, but in eastern areas, temperatures are higher and growth duration less and two rice crops and one wheat crop is possible. Or in lower lying areas two or three rice crops are grown in a year.

Rice in the rice-wheat system is normally seeded in late May and June and transplanted in late June through July. Harvest can be as early as October and continue through November, especially where photosensitive local or quality rice is grown (e.g., *Basmati* rice). Wheat can be planted as early as late October, is best planted in mid-November and can be planted late in December or even January. Harvest starts in March in the east and continues into May in the west.

The most common problems identified from the various diagnostic surveys are listed in Table 1. Each of these will be discussed in the following text with some researchable issues and solutions suggested. Some are simply issues for the single commodity programs and are presently being researched. Others have a systems perspective and these will be highlighted here.

One of the major problems of this system is the completely different way that rice and wheat soils are managed. Transplanting rice seedlings into puddled soils is the traditional way to grow rice in this region (soils plowed when wet). There is some dry seeded, non-puddled rice but this is mainly found in rainfed areas. The puddling is done to restrict water percolation and losses and through the water better control the weeds. This is optimal for rice, but does create problems for the following wheat crop that are planted into physically degraded, puddled rice soils. The repeated cycle of wet puddling soils for transplanted rice over many years has led to several problems. These include the deterioration of soil physical structure, formation of a hard pan at a shallow depth, poor infiltration and waterlogging and poor rooting. It is also one of the main causes for late planting of wheat since farmers need to plow their fields many times to get a good seedbed for planting wheat. The lack of soil physical structure produces a cloddy structure when medium to heavy puddled soils is plowed. This excessive tillage and poor soil structure also creates a problem during the first irrigation. Water stands in the plot due to poor

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infiltration, oxygen stress occurs and wheat plants turns yellow and are stunted and set back in growth.

One solution to this problem is zero-tillage. This is described in another chapter. In this system, wheat is planted into the rice stubble with minimum disturbance. This can be done from merely broadcasting the seed on the surface to use of planting equipment designed to place seed in the soil without tillage. Results are impressive and farmers who adopt this technology are describing a whole array of benefits. These range from cost and fuel saving, to better yield, no yellowing after irrigation, less weeds, less water needed and less lodging. There are also many environmental benefits including less carbon emissions and less global warming, less herbicide and water use. This solution overcomes the problem of late planting and poor plant stands.

Another research tact is to do away with puddling in soils where this is not needed (heavy, poor draining low land and salt affected soils). Weeds become a major issue in this case and weed strategies are needed to overcome this new problem. Use of integrated weed management is a key to solve this problem. Without puddling, soil physical poperties are improved and the subsequent wheat crop, especially with zero-till is much better.

Nutrient imbalance and mining by rice and wheat has led to problems in some areas. Both these cereal crops are heavy users of nutrients. In many areas, most of the crop residues are removed for animal or fuel use, especially in the east. Nitrogen and phosphorus are two of the most important macro-nutrients that become limiting in the rice-wheat system. Of course application of fertilizer, either organic or inorganic or a combination of the two can overcome this problem. Potassium is also starting to become limiting in some rice-wheat areas. This element is usually present in adequate amounts in the IGP soils, but because many farmers remove the entire residue and don't apply potassium, this imbalance is leading to deficiency. Zinc, boron, manganese are micronutrient problems in some areas. Boron leads to sterility in wheat and zinc is essential for rice yield in some areas, especially where there are alkaline soils. Soil organic matter declines have been suggested as a problem with the rice-wheat system. The use of organic fertilizers in combination with inorganic ones shows better results. However, organic manures are in short supply since they are needed for fuel purposes and it is costly to transport to the fields. Some long-term experiment results also indicate that organic matter

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can increase or stabilize over time in this system (Duxbury et al., 2000).

Solutions to this nutrient problem are found in finding ways to more efficiently utilize applied nutrients. This is also covered in another chapter. Essentially a system is needed to maintain a balance between what is supplied and what is removed. Studies are underway to determine the nutrient supplying capacity of individual soils. Based on this a recommendation can be calculated on how much external nutrients are needed to meet a certain yield level without causing a soil imbalance.

Continuous rice-wheat has led to buildups of pest and diseases of rice and wheat. One of the best examples of this is the spread of the grassy weed, *Phalaris minor.* This is a major problem in NW India, where this weed has developed resistance to the commonly used herbicide, *Isoproturon*™. Use of new reduced tillage options can help since the soil is not disturbed and weeds germinate less. Also through timely planting, the wheat can emerge and then shade out the later planted weed plants. Use of bed planting can be used to reduce the weed population while reducing herbicide use. New herbicides are also available, but their cost is high and they are also susceptible to herbicide resistant weeds. Rotations with other crops are also a viable integrated strategy to adopt in rice-wheat systems. Stemborer issues in zero-tillage wheat have been raised as a possible problem if these new technologies are adopted. This is being closely monitored but initial data indicates this is less of a problem than anticipated. In fact in zero-tillage where the residues are left on the surface and not buried, beneficial insects have a better habitat and survive to reduce this insect problem. The occurrence of diseases that carryover from rice to wheat and are perpetuated by the system are less than anticipated although they are being monitored, both foliar and soil pathogens.

Issues of water management figure high in this system. Many farmers list water stress as an issue. Water pricing policy is to blame in some areas, since the incorrect policy can lead to misuse of this natural resource. In many areas of NW India and Pakistan water tables are declining rapidly as more water is removed than replaced. This is obviously not a sustainable situation. In other areas water tables are rising and leading to waterlogging or salinity/sodicity. Sound water use policies and good water management strategies are needed. Watershed water balance studies are needed at the macro-level. At the

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field level, zero-tillage, bed planting, laser leveling and dry seeded rice are being monitored as ways to improve water use efficiency.

Varietal use is another problem in the rice-wheat system. This is especially a problem in areas where late maturing rice varieties are grown. *Basmati* rice is high quality scented rice grown in NW India and Pakistan (80% in Punjab Pakistan). It matures in November and therefore interferes with timely wheat planting. Researchers are working to find shorter duration *Basmati* rice varieties but at the moment farmers must reduce turnaround time using reduced tillage techniques to overcome this problem.

In India, in addition to the agronomic reasons, the yearly declaration of a remunerative support purchase price for rice and wheat by the government has helped the rice-wheat rotation to spread from west to east. This spread has happened in many states in India by displacing a sizeable area under legumes and other less productive crops, e.g., oilseeds and millets. Obviously policy is a major issue in rice-wheat systems.

A majority of the farmers save their own seeds for planting the following year. Farmers cite this as a factor that limits optimum plant population. This is more of a problem for wheat because wheat seeds need to be stored through the hot and humid summer months and then directly seeded at the time of planting. Rice seeds are stored through the cooler and less humid winter months and secondly, only germinated and healthy rice seedlings are transplanted, therefore, rice seed quality for transplanted rice is less of a concern than wheat seed quality.

It is ironic that in a region that supports more than a billion people, labor shortages during the major cultural operations, i.e., at planting, harvesting and threshing is increasing. Renting of farm equipments in the northwestern IGP and the adoption of small-scale mechanization in the eastern IGP is increasing. In the northwestern IGP, renting of tractors for land preparation, and combine harvesters for harvesting rice and wheat is common. The use of locally manufactured threshers for wheat and rice is more common in the western IGP compared to the eastern IGP. It is envisaged that with the introduction and spread of two-wheeled hand operated tractors in the eastern IGP for the major cultural operations, labor shortages will be overcome to some extent. Though substantial improvements have been made in the availability of credit for farmers, farmers still cite the easy and timely access to

credit and effective marketing of their produce as a major limitation in their overall farming needs.

PRODUCTIVITY OF THE RICE-WHEAT CROPPING SYSTEM

The total production of rice and wheat in South Asia has been increasing on a yearly basis, but there are concerns that the productivity of this system is either stagnating or declining. Productivity trend analysis can be done on a regional scale based on published government statistics, at the farm level to understand changes in farmers field through long-term farm monitoring, or on research stations based on the data of long-term experiments. This section summarizes results from reports of productivity analysis done on data reported in government publications (Chand, 1999; Chand and Haque, 1998; Hobbs and Morris, 1996; Indian Council of Agricultural Research, 1998; Kumar et al., 1998).

Changes in the yield trend of a cropping system should be studied in terms of the inputs used, to make a realistic assessment of the productivity of a cropping system. Few total (TFP) and partial factor productivity (PFP) analyses have been done for the rice-wheat cropping system of South Asia as a measure of sustainability. A positive trend in the factor productivity over several years of a cropping system would indicate increases in the quantity and quality of input used, and favorable changes in the technological, physical and economic environment (Harrington et al., 1992). Hobbs and Morris (1996) have appropriately summarized the factor productivity studies done on rice-wheat cropping system prior to 1996. The few TFP studies on rice-wheat cropping system indicate a declining or a negative productivity for the system (Ali and Velasco, 1994; Cassman and Pingali, 1995) due to deterioration of resources, and changes in the physical and chemical properties of the soil thereby reducing nitrogen-supply capacity of the soil. PFP studies also indicate a decline in the productivity of the rice-wheat system (Byerlee and Siddique, 1994; Kumar and Rosegrant, 1994). The TFP analyses done by Kumar et al. (1998) shows a declining productivity in the IGP region of India. The authors argue that the yield growth has been more input based, and higher growth in yield and production in the IGP is only possible through better management of existing soil and water resources. Pingali and Heisey (1999) have also made similar conclusions during their analyses of

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cereal crop productivity of developing countries. Therefore, in intensively cultivated areas where two or more cereal crops are grown in a rotation, there is evidence of finite resource base limiting productivity growth (Pingali and Heisey, 1999), and its growth can only be sustained by conserving the natural resource base, increasing input use efficiency, and by increasing the investments in agricultural research and education.

CONCLUSIONS

To conclude, the rice-wheat systems are here to stay. They are a major source of cereal food production in the region and it will be difficult to replace them. Farmers find very few substitutes for rice and wheat that provide similar low risk and profit. Research has to find ways of sustaining this system and making it more efficient and profitable. Continued growth in rice and wheat area is very unlikely since in the future there will be more competition for domestic and industrial uses. This leaves just yield growth available to increase production growth. The use of cost reducing, more efficient systems will be required if agriculture in the region is to keep pace with population demand and food security is to be maintained.

REFERENCES

Adhikari, C.A., C.B. Adhikary, N.P. Rajbhandari, M. Hooper, H.K. Upreti, B.K. Gyawali, N.K. Rajbhandari, and P.R. Hobbs. (1999). *Wheat and Rice in the Mid-Hills of Nepal*: *A Benchmark Report on Farm Resources and Production Practices in Kavre District*. *Kathmandu*: NARC and CIMMYT, pp. 1-26.

Ahmed, N.U., M.M. Alam, A.M. Bhuiyan, R. Islam, and M.U. Ghani. (1993). *Rice Wheat Diagnostic Survey in Greater Kushtia District of Bangladesh*. Rice Farming Systems Division, Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh, pp. 1-57.

Ali, M., and L.E. Velasco. (1994). *Intensification of Induced Resource Degradation*: *The Crop Production Sector in Pakistan*. Los Banos, Phillipines: International Rice Research Institute (IRRI). Mimeo.

Baksh, Md.E., and M.A. Razzaue. (1999). *Diagnostic Survey Report on Rice-Wheat system at Dinajpur and Rangpur Districts*. Wheat Research Centre, Bangladesh Agricultural Research Institute, Nashipur, Dinajpur, pp. 1-38.

Bhuiyan, A.M., M. Badaruddin, N.U. Ahmed, and M.A. Razzaque. (1993). *Rice-Wheat System Research in Bangladesh*: *A Review.* Bangladesh Rice Research Institute and Bangladesh Agricultural Research Institute, pp. 1-96.

Biswas, T.D., and G. Narayanaswamy. (1997). Sustainable Soil Productivity Under Rice-Wheat System. *Indian Society of Soil Science* Bulletin No. 18, pp. 1-83.

Byerlee, D., A.D. Sheikh, M. Aslam, and P.R. Hobbs. (1984). *Wheat in the Rice-Based Farming System of the Punjab*: *Implications for Research and Extension*. AERU, NARC and CIMMYT, Pakistan.

Byerlee, D., and A. Siddique. (1994). Has the Green Revolution been sustained? The quantitative impact of the seed-fertilizer revolution in Pakistan revisited. *World Development*. 22(9): pp. 1345-1361.

Cassman, K.G., and P.L. Pingali. (1995). Extrapolating trends from long-term experiments to farmers' fields: The case of irrigated rice systems in Asia. pp. 63-84. In *Agricultural Sustainability*: *Economic, Environmental, and Statistical Considerations*, eds. V. Barnett, R. Payne, and R. Steiner, London, U.K.: John Wiley,

Chand R. (1999). Emerging Crisis in Punjab agriculture: Severity and options for future. *Economic and Political Weekly.* March 27, pp. A2-10.

Chand R., and T. Haque. (1998). Rice-wheat crop system in Indo-Gangetic Region: Issues concerning sustainability. *Economic and Political Weekly.* Vol 33 (29): pp. A108-12.

Dhiman, S.D., M.K. Chaudhary, D. Singh, H. Om, D.P. Mandal, D. Singh, and D.V.S. Panwar. (1999). *Measuring Sustainability of Rice-Wheat Cropping System Through On-Farm Monitoring in Haryana*. CCS Haryana Agricultural University, Rice Research Station, Kaul, Regional Research Station, Karnal publication, p. 37.

Duxbury, J.M., I.P. Abrol, R.K. Gupta, and K.F. Bronson. (2000). Analysis of soil fertility experiments with rice-wheat rotations in South Asia. In *Long Term Soil Fertility Experiments in Rice-Wheat Cropping Systems*, eds. I.P. Abrol, K.F. Bronson, J.M. Duxbury and R.K. Gupta. Rice-wheat consortium paper series number 6. New Delhi, India. RWC for IGP.

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

Gami, S.K., B. Chaudhary, and M.P. Shah. (1997). *Rice-Wheat Diagnostic Survey in Rauthat District of Nepal*. Nepal Agricultural Research Council and SM-CRSP Cornell University, USA, pp. 1-39.

Harrington, L.W., S. Fujisaka, P.R. Hobbs, C. Adhikary, G.S. Giri, and K. Cassaday. (1993a). *Rice-Wheat Cropping System in Rupandehi District of the Nepal Terai*: *Diagnostic Surveys of Farmers' Practices and Problems, and Needs for Further Research*, Mexico, D.F.: CIMMYT, NARC, and IRRI, pp. 1-33.

Harrington, L.W., P.R. Hobbs, K.A. Cassaday, eds. (1992). *Methods of Measuring Sustainability Through Farmer Monitoring*: *Application to the Rice-Wheat Cropping Pattern in South Asia*. Proceedings of the workshop, 6-9 May, 1992, Kathmandu, Nepal. Mexico, D.F.: *CIMMYT, IRRI and NARC*, pp. 1-111.

Harrington, L.W., P.R. Hobbs, D.B. Tamang, C. Adhikari, B.K. Gyawali, G. Pradhan, B.K. Batsa, J.D. Ranjit, M. Ruckstuhl, Y.G. Khadka, and M.L. Baidya. (1993b). *Wheat and Rice in the Hills*: *Farming Systems, Production Techniques and Research Issues for Rice-Wheat Cropping Patterns in the Mid-Hills of Nepal*. Report on an exploratory survey conducted in Kabhre district, 20-28 April 1992. *NARC CIMMYT.* Mexico DF. 84 p.

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Harrington, L.W., S. Fujisaka, M.L. Morris, P.R. Hobbs, H.C. Sharma, R.P. Singh, M.K. Chaudhary, and S.D. Dhiman. (1993c). *Wheat and Rice in Karnal and Kurukshetra Districts, Haryana, India*: *Farmers' Practices, Problems, and an Agenda for Action*. Mexico D.F. HAU, ICAR, CIMMYT and IRRI.

Hobbs, P.R., G.P. Hettel, R.P. Singh, Y. Singh, L.W. Harrington, and S. Fujisaka. (1990). *Rice-Wheat Cropping Systems in the Tarai Areas of Nainital, Rampur, and Pilibhit Districts in Uttar Pradesh, India*: *Diagnostic Surveys of Farmers' Practices, Problems and Needs for Further Research*. Mexico D.F. ICAR, GBPUAT, CIMMYT and IRRI.

Hobbs, P.R., G.P. Hettel, R.K. Singh, R.P. Singh, L.W. Harrington, V.P. Singh and K.G. Pillai. (1992). *Rice-Wheat Cropping Systems in Faizabad District of Uttar Pradesh, India*: *Diagnostic Surveys of Farmers' Practices, Problems and Needs for Further Research*. Mexico D.F. ICAR, NDUAT, CIMMYT and IRRI.

Hobbs, P.R., L.W. Harrington, C.A. Adhikary, G.S. Giri, S.R. Upadhyay, and B. Adhikary. (1996). *Wheat and Rice in the Nepal Tarai*: *Farm Resources and Production Practices in Rupandehi District*. Mexico, D.F.: NARC and CIMMYT, pp. 1-44.

Hobbs, P., and M. Morris. (1996). *Meeting South Asia's Future Food Requirement from Rice-Wheat Cropping Systems*: *Priority Issues Facing Researchers in the Post-Green Revolution Era*. NRG paper 96-01. Mexico, D.F.: CIMMYT, pp. 1-46.

Inayatullah, C., Ehsan-Ul-Haque, Ata-Ul-Mohsin, A. Rehman, and P.R. Hobbs. (1989). *Management of Rice Stem Borers and the Feasibility of Adopting No-Tillage in Wheat*. Entomological Research Laboratories, National Agricultural Research Centre, Pakistan Agricultural Research Council, Islamabad, pp. 1-64.

Indian Council of Agricultural Research. (1998). *Decline in Crop Productivity in Haryana and Punjab*: *Myth or Reality.* Report of the Fact Finding Committee May 1998, pp. 1-90.

Kumar, P., and M.W. Rosegrant. (1994). Productivity and sources of growth for rice in India. *Economic and Political Weekly.* 29(53): A183-A188.

Kumar, P., P.K. Joshi, C. Johansen, and M. Asokan. (1998). Sustainability of Rice-Wheat Based Cropping Systems in India: Socio-Economic and Policy Issues. *Economic and Political Weekly.* (26): pp. A152-58.

Meisner, C.A. (1992). *Report of an On-Farm Survey of the Mymensingh Region and Tangail Wheat Growers' Practices, Perceptions, and Their Implications. Monograph No. 9*. Bangladesh Agricultural Research Institute, Wheat Research Centre, Nashipur, Dinajpur, pp. 1-31.

Meisner, C.A. (1996). *Report of an On-Farm Survey of the Greater Comilla Region Wheat Growers' Practices, Perceptions, and Their Implications. Monograph No. 13*. Bangladesh Agricultural Research Institute, Wheat Research Centre, Nashipur, Dinajpur, pp. 1-34.

Paroda, R.S., T. Woodhead, and R.B. Singh. (1994). *Sustainability of Rice-Wheat Production Systems in Asia*, RAPA Publication 1994/11, pp. 1-209.

Pingali, P.L., and P.W. Heisey. (1999). *Cereal Crop Productivity in Developing Countries*. CIMMYT Economics Papers 99-03. Mexico D.F.: CIMMYT. pp. 1-32.

Ranjit, J.D., N.K. Rajbhandari, R. Bellinder, and P. Kataki. (1999). *Mapping Phalaris minor in the Rice-Wheat Cropping System of Different Agro-Ecological Regions*

of Nepal. Nepal Agricultural Research Council, Nepal and SM-CRSP Cornell University, USA, pp. 1-65.

Razzaque, M.A., M. Badaruddin, C.A. Meisner, eds. (1995). *Sustainability of Rice-Wheat Systems in Bangladesh. Proceedings of the Workshop*. Bangladesh Agricultural Research Institute, Bangladesh Rice Research Institute and Bangladesh Australia Wheat Improvement Project, pp. 1-113.

Saunders, D.A. (1990). *Report of an On-Farm Survey Dinajpur District Wheat Farmers' Practices and Perceptions*. *Monograph No. 6*. Bangladesh Agricultural Research Institute, Wheat Research Centre, Nashipur, Dinajpur, pp. 1-38.

Saunders, D.A. (1991). *Report of an On-Farm Survey Jessore and Kushtia Wheat Farmers' Practices and Perceptions*. *Monograph No. 8*. Bangladesh Agricultural Research Institute, Wheat Research Centre, Nashipur, Dinajpur, pp. 1-30.

Singh, R.A., R.M. Singh, H.P. Agrawal, S. Nagarajan. (1996). *Rice-Wheat Cropping System in Varanasi District, Uttar Pradesh, India*, Research Bulletin No. 3, Directorate of Wheat Research, Karnal, India, pp. 1-116.

Yadav, R.L., K.S. Gangwar, and K. Prasad. (1998). *Dynamics of Rice-Wheat Cropping System in India*. Technical Bulletin, Modipuram, Meerut, India, Project Directorate for Cropping Systems Research, pp. 1-90.

Yadav, R.L., K. Prasad, and K.S. Gangwar. (1998). *Analysis of Eco-Regional Production Constraints in Rice-Wheat Cropping Systems Research*, Modipuram, Meerut, India, Project Directorate for Cropping Systems Research, pp. 1-68.

Yadav, R.L., K. Prasad, and A.K. Singh (eds.). (1998). *Predominant Cropping Systems of India*: *Technologies and Strategies*. Modipuram, Meerut, India, Project Directorate for Cropping Systems Research, pp. 1-237.

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