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Rice–Wheat in South Asia: Systems and Long-Term Priorities Established Through Diagnostic Research*

Sam Fujisaka‡

International Rice Research Institute (IRRI),
P.O. Box 933, Manila, The Philippines

Larry Harrington

International Maize and Wheat Improvement Center (CIMMYT),
Apdo. Postal 6-641, Mexico

&

Peter Hobbs

International Maize and Wheat Improvement Center (CIMMYT),
P.O. Box 518, Kathmandu, Nepal

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ABSTRACT

Rice and wheat are grown in rotation on about 12 million hectares in South Asia. Yields in this rotation have increased over time, but evidence indicates that factor productivity may be declining. Recently, multidisciplinary teams of agricultural scientists conducted diagnostic surveys in several rice–wheat areas in South Asia. This paper reviews rice–wheat system problems and longer-term issues of sustainability identified through the surveys (near-term problems affecting rice and wheat yields are discussed less fully). System problems include poor wheat populations caused by the poor soil structure and plow pan formed for puddled rice, late wheat planting resulting from late rice harvesting, and losses to grassy weeds encouraged by continuous rice–wheat cultivation. Sustainability issues include soil nutrient depletion and possible buildup of insects, weeds, and diseases.

* The views expressed in this paper are the authors' and should not necessarily be attributed to IRRI or CIMMYT.
‡ Present address: Centro Internacional de Agricultura Tropical (CIAT), Apdo. Aereo 6713, Cali, Colombia.

INTRODUCTION

Rice and wheat are grown in rotation on approximately 9 m ha (million hectares) in India, 1·5 m ha in Pakistan, 0·6 m ha in Bangladesh, and 0·5 m ha in Nepal (IRRI, 1992). In the wet or summer season, farmers normally transplant rice in puddled soils, although wet-seeded and dry-seeded rice have been observed in some areas. After rice, in the dry or winter season, wheat is usually broadcast sown, typically after a thorough land preparation and at least some irrigation. Some farmers produce two rice crops and a wheat crop (e.g. in parts of Bangladesh). Crop mixtures that include wheat and mustard, and rotations with sugarcane, are found throughout the rice–wheat area. Where animal and dairy production are important, fodder crops such as berseem clover (*Trifolium alexandrinum*) compete with wheat for land in the winter cycle.

Given that the rice–wheat pattern is an important, even predominant, source of income for tens of millions of farm families in some of the world's poorest areas, any threat to the productivity of this system must be taken seriously. Although rice and wheat yields in the rice–wheat belt of South Asia have increased over time, there is evidence that factor productivity (i.e. yields at constant levels of inputs) may be declining (IRRI, 1990). Negative trends in factor productivity commonly are interpreted as threats to the sustainability of a system (Lynam & Herdt, 1988). These trends have not been confirmed fully, but are cause for concern.

Partly in response to this concern, a collaborative project was initiated by scientists from the International Rice Research Institute (IRRI), the International Maize and Wheat Improvement Center (CIMMYT), and national agricultural research systems (NARSs) of Bangladesh, India, Nepal, and Pakistan. The project seeks ways in which improvements in agricultural technology can foster increased productivity and profitability of the rice–wheat systems in South Asia, while safeguarding the quality of agricultural resources devoted to this system. As a first step towards this goal, project participants conducted a series of 'diagnostic surveys' in three rice–wheat areas. (The phrase 'diagnostic survey' is restricted to surveys following rapid rural appraisal techniques conducted by IRRI–CIMMYT–NARS teams as part of the collaborative rice–wheat project.) This paper synthesizes data from the diagnostic surveys and earlier surveys in Pakistan and Bangladesh to describe the rice–wheat system and identify problems affecting rice and wheat. The discussion focuses on system level problems, longer-term sustainability issues, and suggested research priorities identified and defined through the diagnostic surveys.

METHODS

Diagnostic surveys

Multidisciplinary teams of 15–20 IRRI, CIMMYT, and NARS scientists, working in pairs, conducted diagnostic surveys during the rice and wheat seasons in three areas: (1) Nainital, Rampur, and Pilibhit Districts of Uttar Pradesh, India, henceforth referred to as 'Pantnagar' (Hobbs *et al.*, 1990); (2) Faizabad District of Uttar Pradesh (Hobbs *et al.*, 1991); and (3) Rupandehi District in the terai (lowlands) of Nepal (Harrington *et al.*, 1990, 1993). The surveys lasted one to two weeks, featured informal but structured farmer interviews, and covered farmers' practices and knowledge, levels of inputs and yields, field observations, and problem identification.

The relative importance of problems was estimated by scoring each farmer- and researcher-identified problem in terms of percentage area affected, percentage frequency of occurrence, and percentage productivity loss (broadly defined to include productivity loss attributable to inefficient input or resource use). Scoring ranges (see Table 1) were established for each criterion in order to assign scores of 0, 1, 2, or 3. A zero score (denoting minimal occurrence of a problem over space or time, or minimal productivity loss) eliminated the problem from further consideration. A question mark was entered if data were insufficient to make an assessment.

Most problems were identified and prioritized by both researchers and farmers in the sense that researchers based prioritization decisions largely on farmers' accounts and joint visits to farmers' fields. In some cases, however, researchers included problems *not* identified by farmers (e.g. inefficient fertilizer or pesticide use). These researcher-identified problems were based on field observation and analysis of farmers' descriptions of their crop and resource management practices.

Scores for well defined problems (those without zero scores or question marks) were summed over the three criteria. These problems were then divided into three levels of priority, in which higher priority corresponded to larger sums of scores. This method of ranking possesses two advantages. Firstly, the process whereby one problem is given priority over another is transparent; secondly, priorities may be reassessed readily when further information on the scoring criteria is available.

Opportunities for research and extension interventions were identified by defining and diagramming the causes of major problems, including interactions among problems and ways in which farming systems parameters contributed to problems (Tripp & Woolley, 1989; Fujisaka, 1991;

TABLE 1
Scoring and Ranking of Problems Identified for Rice in the Rice–Wheat System, Pantnagar, India

Problem	*Per cent of years*[a]	*Yield loss of*	*Per cent of farms*	*Large versus small*	*Score*	*Rank*
Nutrient depletion	3	1	3	2	9	I
Rats	3	1	2	2	8	I
Brown planthopper	2	1	2	2	7	II
Inefficient fertilizer use	3	1	2	1	7	II
Bacterial leaf blight	1	2	1	2	6	II
Delayed rice transplanting	2	1	1	1	5	III
Yellow stemborer	3	0	3	2	0	
Inefficient pesticide use	3	0	2	2	0	
Sheath blight	1	?	?	2	?	?
Waterlogging	2	?	?	2	?	?
Nematodes	3	?	3	2	?	?

[a] Scoring:

Score	*Years (%)*	*Yield (%)*	*Farms*	*Size*
0	0–10	0–5	0–5	Large
1	10–40	5–15	5–15	Large
2	40–80	15–50	15–50	Both
3	>80	>50	>50	Small

Source: Fujisaka, S. & Diagnostic Survey Team (1990). Rice–wheat diagnostic survey: Pantnagar, India rice-season survey. Unpublished report.

Harrington, 1991). It was found that an understanding of causes was important in suggesting alternative ways to address major problems. Diagnostic surveys also provided information useful in screening research and extension interventions for feasibility (in terms of local and project research resources) and for relevance to farmers' conditions.

Other surveys

CIMMYT and NARS wheat scientists and agricultural economists surveyed 152 farmers in the Punjab of Pakistan early in the 1984 wheat season, obtaining information on farm characteristics, farming systems, and farming practices, including weed scores, crop cuts, and other direct field observations (Byerlee *et al.*, 1984). A 1990 study in the same area surveyed 90 farmers after crop establishment and after harvest of both rice and wheat (Sharif *et al.*, 1992). Other surveys on rice and wheat in the Punjab of Pakistan are also reported (Akhtar *et al.*, 1987; Hobbs *et al.*, 1987; Ahmad *et al.*, 1988; Sharif *et al.*, 1988*a,b,c,d*; Aslam *et al.*, 1989; Azeem *et al.*, 1989).

Scientists of the Rice Research Institute (Dokri) and IRRI surveyed 100 rice–wheat farmers in Larkana and Dadu Districts of the Upper Sind, Pakistan, in 1987. Farmers were interviewed after rice harvest, after wheat seeding, and after wheat harvest (Bhatti *et al.*, 1987). Flinn and Khokhar (1989) further analyzed that system. Bhatti *et al.* (1986) examined rice management in the same area.

Twenty-three scientists of the Bangladesh Agricultural Research Institute and CIMMYT surveyed 200 farmers in Dinajpur District after wheat crop establishment in 1990 (Saunders, 1990). A similar survey of 202 farmers by a larger group took place in Jessore and Kushtia Districts after wheat establishment in 1991 (Saunders, 1991).

RESULTS

The rice–wheat system

All the area under the rice–wheat system in Pakistan is irrigated; annual rainfall averages only 120 mm in the Upper Sind and 400–800 mm in the Punjab. In Bangladesh, India, and Nepal, about 60–90% of the rice–wheat area is irrigated (average rainfall ranges from 1100 mm in Pantnagar to 1800 mm in Dinajpur). These areas include some tracts of fully rainfed wheat as well as places where only supplemental irrigation is available. Drought affects both rice and wheat in Faizabad (India) and Rupandehi (Nepal), where only two-thirds of the area is irrigated (Table 2).

Soils and hydrological features vary among and within surveyed rice–wheat areas. In general, low-lying areas with poor drainage and heavy soils are poorly suited to wheat and better suited to traditional rice cultivars than to improved ones. Slightly higher, better drained areas usually have lighter soils and are better suited to wheat and some competing crops, such as sugarcane. In the absence of irrigation, however, rice in these areas often suffers from drought late in the growing season.

Crop rotations in major rice–wheat areas are not restricted entirely to rice and wheat. In Faizabad and Pantnagar, rotations also include sugarcane and sugarcane ratoons. In all rice–wheat areas of South Asia,

TABLE 2
National Rice–Wheat Area, Percent Area Irrigated, Mean Annual Rainfall, and Mean Farm Size in the Survey Areas of India, Pakistan, Nepal, and Pakistan

Country	*National rice–wheat area*[a] *(m ha)*	*Survey areas*			
		Site	*Irrigated area (%)*	*Mean annual rainfall (mm)*	*Mean farm size (ha)*
India	9·0	Pantnagar, U.P.	80	1100	8·9
		Faizabad, U.P.	65	1200	—
Pakistan	1·5	Punjab	100	400	6·8
		Larkana and Dadu, Sind	100	120	2·3
Nepal	0·5	Rupandehi District	60	1600	2·0
Bangladesh	0·6	Jessore and Kushtia	90	—	2·0
		Dinajpur	70	1800	2·0

[a] Source: IRRI (1992).
U.P., Uttar Pradesh.

oilseeds (mustard, flax, and sunflower) are grown in the winter for domestic cooking oil. Often mustard is mixed with the wheat crop; before the wheat harvest, mustard is removed for fodder or oil. In rice–wheat areas of Pakistan and India, berseem is an important fodder crop where dairying is a farm enterprise. Winter crops that follow rice in the Nepal terai include wheat and mustard mixtures as well as grain legumes, especially lentils, which are often mixed with flax and/or mustard. Finally, cropping patterns in rice–wheat areas of Bangladesh include jute–rice–wheat and rice–rice–wheat as well as rice–wheat. Rice in the rice–wheat sequence is normally seeded in May–June, transplanted in June–July, and harvested in October (although basmati rice in Pakistan and India is harvested in November). Wheat is sown between mid-November and early January and harvested in April or May.

Farm size varies greatly within all of the survey areas (Table 2). Farms are relatively larger in Pantnagar (averaging around 9 ha) and in Pakistan's Punjab (around 7 ha), and are smaller in Nepal and Bangladesh (around 2 ha). The Sind has small farms (2 ha) but also many large landholdings cropped by tenant farmers. Tractor use is more widespread on larger farms. In Pantnagar, for example, 69% of the farmers who have more than 4 ha own tractors (Hobbs *et al.*, 1990), and in the Punjab of Pakistan, 79% of the farmers surveyed use tractors (Sharif *et al.*, 1992).

However, in Nepal and Bangladesh, tractor use ranges from virtually none in the Nepal terai and Dinajpur to about 27% of surveyed farmers (using partial mechanization) in Jessore and Kushtia (Saunders, 1990, 1991).

Rice practices and near-term problems

The rice varieties grown by farmers vary immensely. A number of improved materials are grown (Pant Dhan-4 in Pantnagar, Basmati-385 in the Punjab of Pakistan, IRRI-6 in the Sind), including the farmer-developed, improved Indrasan in Pantnagar. One common rice variety is the indica × japonica rice called 'Masuli' or 'Pajam' (Bangladesh). Many local cultivars are grown as well.

Rice yields in the main season ranged from 3·0 t/ha (measured from crop cuts) in the Punjab of Pakistan to 5·8 t/ha in Pantnagar (estimated by farmers). (The lower yields in Pakistan are influenced by the large area planted to low-yielding but higher quality basmati rices.) Yields tend to increase with higher doses of inorganic fertilizer. Farmers in

TABLE 3
Rice Yields, Inorganic Fertilizer Applied to Rice, Farm Yard Manure Applied to Rice–Wheat Fields, and Main Rice Varieties in the Survey Areas

Country and survey area	*Yield (t/ha)*	*N–P_2O_5–K_2O (kg/ha)*	*FYM (t/ha)*	*Main rice varieties*
India				
Pantnagar, U.P.	5·8	100–85–35	Low	Pant Dhan-4, Indrasan
Faizabad, U.P.		100–45–00	Low	Masuli and mixed local
Pakistan				
Punjab	3·0	55–35–00	4·0	Basmati-385
Larkana and Dadu, Sind	4·3	80–55–00	0·0	IR-6
Nepal				
Rupandehi	3·0	35–15–00	4·0	Mixed local and improved
Bangladesh				
Jessore and Kushtia	4·3	95–25–35	10·5	62% farmers' *Aman* rices[a]
	2·3	45–15–20	—	42% farmers' *Aus* rices[a]
Dinajpur	3·2	45–35–20	5·5	80% farmers' *Aman* rices
	2·4	30–30–15	—	34% farmers' Aus rices

[a] In Bangladesh, *Aman* is the main growing season for rice, and *Aus* is the secondary growing season.
U.P., Uttar Pradesh.

Pakistan's Punjab who obtain 3·0 t/ha of rice apply an average 55 kg N and 35 kg P_2O5/ha. In contrast, Pantnagar farmers obtaining 5·8 t/ha apply 100 kg N, 85 kg P_2O_5, and 35 kg K_2O/ha (Table 3). The reported effects of farm yard manure (FYM) on yield are less conclusive, most likely because of large differences in farmers' FYM management strategies (some farmers restrict FYM use to the *poorest* rice–wheat fields to build up fertility).

Pest (insect, weed, disease, and rat) and soil nutrient problems appear to reduce rice yields at the various sites. Other near-term problems affecting rice include poor plant stand (typically caused by drought or the use of contract labor for transplanting) and late transplanting of old seedlings.[†]

Problems hypothesized to be associated with soil fertility include possible deficiencies of zinc and potassium in Pantnagar and Faizabad and nitrogen, phosphate, and zinc deficiencies in Nepal.

The diagnostic surveys conducted during the rice season in Pantnagar, Faizabad, and Rupandehi include suggested research or extension interventions that might be fruitfully pursued by national programs to address the problems described above. Examples are listed in Table 4.

Wheat practices and near-term problems

Farmers in all major rice–wheat areas primarily use improved wheat varieties: HD-2329, HD-2285, UP-2003, UP-262, and RR-21 in India and Nepal; Pak-81, Pavon-76, and Shalimar-85 in Pakistan; and Kanchan and Akbar in Bangladesh. Some farmers continue to grow the older improved varieties (e.g. Sonalika or RR-21, Pak-70, and Pavon-76), although recent problems with leaf rust (*Puccinia recondita*) and *Helminthosporium* leaf blight in RR-21 and Pak-70 have reduced the area sown to these varieties. The old, quality wheat variety C-591 is still grown in some areas of the Sind. Wheat yields average about 2·0 t/ha, ranging from 1·7 to 2·3 t/ha in Faizabad, the Punjab of Pakistan, the Sind, the Nepal terai, and dryland areas of Bangladesh. Higher yields of around 3·0 t/ha are reported for well irrigated areas in Bangladesh and Pantnagar, and wherever more inorganic fertilizer is used (Table 5).

[†]More specific pest problems in Pantnagar include brown planthopper (*Nilaparvata lugens*), exacerbated by susceptible cultivars, standing water, and high nitrogen applications; bacterial leaf blight or BLB (*Xanthomonas campestris* pv. *oryzae*); and rats. Major problems in Faizabad include weeds (especially *Echinochloa* and *Cyperus* spp.) and rats. Lesser problems at that site include armyworm (*Mythimna separata*), ricebug (*Leptocorisa oratorius*), BLB, sheath blight (*Rhizoctonia solani*), and brown spot (*Helminthosporium oryzeae*). Rice pests in Nepal include weeds, BLB, ricebug, caseworm (*Nymphula depunctalis*), nematodes (*Hirschmaniella oryzae*), and rats.

TABLE 4
Research Areas/Topics Suggested by Results of Diagnostic Surveys in Pantnagar, Faizabad, and Rupandehi

Suggested research	*Pantnagar*	*Faizabad*	*Rupandehi*
Brown planthopper (BPH) resistant varieties	+	–	–
BPH forecasting and natural enemies	+	–	–
Bacterial leaf blight/disease resistance and management	+	+	+
Direct-seeded rice and wet-seeded rice as alternatives to transplanted rice	+	–	–
Water management, balance, and hydrology	–	+	+
Management and cultivars for drought	–	+	+
Weed loss assessment	–	+	+
Management (rotations, FYM) effect on weeds	–	+	+
Herbicide use	–	+	+
Poor plant stand due to direct seeding of rice, poor transplanted rice	–	+	–
Rats; management and postharvest storage	–	+	+
Zinc deficiency and management alternatives	+	+	+
Pest and disease build-up	–	+	+

The symbol '+' denotes that the research was needed; '–' denotes the opposite.

TABLE 5
Wheat Yields, Inorganic Fertilizer Applied to Wheat, and Main Wheat Varieties in the Surveyed Areas

Country and survey area	*Yield (t/ha)*	*N–P_2O_5–K_2O (kg/ha)*	*Main wheat varieties*
India			
Pantnagar, U.P.	3·3	100–50–00	HD-2329, UP-2003, HD-2285, RR-21
Faizabad, U.P.	2·3	65–50–00	RR-21, UP-262, others
Pakistan			
Punjab	1·8	30–20–00	Pak-81, Shalimar-85
Larkana and Dadu, Sind	2·1	70–50–00	Pak-70, C591, Pavan-76, Sonalika
Nepal			
Rupandehi	1·7	55–30–00	RR-21, UP-262, Siddartha, Vinayak, NL-297
Bangladesh			
Jessore and Kushtia	3·0	100–25–25	Kanchan, Akbar
Dinajpur (dryland)	2·0	50–50–25	Sonalika, Kanchan
(irrigated)	2·8	70–55–25	Kanchan, Sonalika

U.P., Uttar Pradesh.

Like rice, wheat suffers losses from rats and weeds. The weed *Phalaris minor* is particularly important in the rice–wheat systems of India and Pakistan, where it appears to be increasing in severity (this grassy weed is not important at sites in Nepal or Bangladesh, however). Other problems stem from the nature of the rice–wheat system itself, particularly late wheat planting and poor wheat plant populations. Wheat planting is often delayed because of the long turn-around time between rice harvest and wheat sowing, when farmers normally conduct many tillage operations. Long turn-around time often is exacerbated by poor field condition. Fields are either excessively wet or excessively dry, or their soil structure is poor after puddling for rice. Late wheat planting is also sometimes traced to late rice harvest, in turn due to the use of long-duration rice cultivars, late transplanting, or late rice planting.

Poor wheat plant populations are also common and are attributed to poor germination, early-season waterlogging, mid-season moisture stress, and nutrient deficiencies that restrict tillering—all of which can be traced partly to the shallow, impermeable plow pan remaining from the previous puddled wet rice crop. Other causes of poor wheat plant populations include over-irrigation or poor water control during irrigation; low-lying fields (or high water tables); and poor rooting caused by soil compaction. Soilborne pests or poor seed quality may also contribute to poor plant populations.

The findings from the diagnostic surveys suggested some research or extension interventions that NARSs might pursue to address near-term, system-wide problems related to wheat (Table 6). Other suggestions focused on ways to address longer-term problems, discussed below.

DISCUSSION AND CONCLUSIONS

Contradictions among potential research themes

Although several interventions were suggested to address the rice–wheat system problems of late wheat sowing and nutrient deficiencies, some of these are contradictory (Table 7). For example, reduced tillage to address the problem of delayed wheat planting will shorten turn-around time between the rice and wheat crops, but it will leave the rice plow pan intact. To break the plow pan, recurrent deep tillage may be needed. Deep tillage will require greater mechanical power; however, the use of heavy tractors can lead to further soil compaction. If the plow pan is broken, water requirements for rice will increase and create problems in areas where water is a limiting factor. Additional rice stubble left by the introduction of zero tillage for wheat may foster higher populations of stemborers, weeds, and other pests. Evidence from Pakistan, however, shows that the concern about overwintering stemborers in rice stubble may be less serious than thought at first (Inayatullah, 1989).

TABLE 6
Suggested Research on Wheat Where a Wheat-Season Diagnostic Survey was Conducted

Problem and suggested research	*Pantnagar*	*Faizabad*	*Rupandehi*
Late wheat planting			
Quantify the problem	–	+	–
Reduced tillage (including mechanized)	+	+	+
Improve health of draft animals	–	–	+
Wheat varieties for late planting	+	–	+
Wet-seeded rice to ensure timely wheat planting	+	+	+
Reduced puddling of rice	+	–	–
Shorter-duration rice varieties	+	–	+
Mechanized rice transplanting	+	–	–
Weeds			
Survey losses to *Phalaris minor*, other weeds	+	+	–
Mechanisms in spread of *P. minor*	–	+	–
Crop rotations to reduce weeds	+	+	–
Use of herbicides	+	+	–
Inadequate water			
Management, water balance, hydrology	–	+	–
Improved wheat varieties	–	–	+
Occasional deep tillage	–	–	+
Waterlogging and excess moisture			
Yield loss assessment	+	–	–
Management, in-field/large-scale drainage	+	–	+
Deep tillage to break plow pan	+	–	+
Zero tillage	+	–	–
Direct-seeded rice or reduced puddling for rice	+	–	+
Nutrient deficiencies			
Discussed as system/long-term problem	+	+	+
Poor plant stand			
Further examine problem and farmers' practice	–	+	–
Importance of soilborne pathogens, insects	–	+	–
Improved tillage	–	–	+
Line sowing (and needed implements)	–	–	+
Wheat seed storage and quality	–	–	+
Rats			
Integrated pest management approaches to rat management	–	+	–

TABLE 7
Tradeoffs Inherent in Solutions to Wheat Problems

Problem	*Solutions/benefits and drawbacks*
Late wheat sowing	*Solution/benefit:* reduced tillage to lessen turn-around time *Drawback:* does not break rice plow pan (see below)
	Solution/benefit: zero wheat tillage to reduce turn-around time *Drawback:* insects and weeds increase
	Solution/benefit: mechanized transplanting to reduce delay in rice establishment *Drawback:* high cost, no suitable machinery, labor displacement(?)
	Solution/benefit: wet-seeded rice would overcome constraints to timely transplanting *Drawback:* more weed control and precise water control needed
	Solution/benefit: shorter-duration rices allow earlier harvest and earlier wheat sowing *Drawback:* reduced rice yields
Waterlogging and nutrient deficiency due to rice plow pan	*Solution/benefit:* periodic deep tillage to draw nutrients from lower soil layers *Drawback:* costly; use of heavy tractors could cause more compaction
	Solution/benefit: reduced rice puddling for transplanted rice to diminish plow pan and prevent soil structure degradation *Drawback:* increased water loss, later drought for rice
	Solution/benefit: dry-seeded rice would eliminate plow pan *Drawback:* need precise timing of sowing versus early-season flooding; increased weeds and later drought

In addition, the shorter-duration rices that facilitate timely wheat sowing usually yield less than longer-duration varieties. These losses must be balanced against the value of increased wheat yields. Reduced puddling of fields for transplanted rice may diminish problems for wheat caused by the rice plow pan, but may lead to increased percolation and to moisture stress for rice at the reproductive stage. Direct seeding of rice would eliminate the plow pan problem for wheat, but direct seeding requires near-perfect timing of sowing and increases problems of weeds and of drought later in the rice season. Dry seeding of rice may speed rice establishment and help achieve timely wheat sowing, but early-season flooding and weed control in the rice crop will become more problematic. Mechanical rice transplanting may also speed establishment of the rice crop, but machinery is costly and not available to farmers. These problems of the rice–wheat system *per se* need to be investigated not only by each national program, but also by the international centers, to develop an overall comparative analysis based on cross-sectional and time-series data.

Long-term problems of the rice–wheat system

Two long-term, rice–wheat system problems are suspected: (1) depletion of soil nutrients; and (2) the build-up of pests—insects, diseases, soil pathogens, and weeds.

Continuous double cropping of cereals, low use of inorganic phosphate and potash in some areas (despite higher nitrogen application rates), reduced use of organic fertilizers (especially FYM), and changes in crop residue management suggest that macro- and micronutrient (Mg, Mn, Fe, Cu, S, and Zn) deficiencies may be more prevalent than in the past. Farmers in Nepal, India, and the Punjab of Pakistan report that FYM applications to the rice–wheat rotation are declining for such reasons as: (1) increased use of FYM for fuel, and (2) reduced livestock populations, given limited grazing areas and increased tractor use (Fig. 1). Livestock populations are lower except where markets allow a cash dairy economy to grow (e.g. near Lahore in Pakistan).

These trends reported by farmers are supported by data from long-term fertilizer trials at Pantnagar and in the Rupandehi District. Rice yields in these trials have declined gradually over more than 10 years, regardless of fertilizer treatment. Wheat yields did not decline as fast as rice yields, remaining relatively stable at recommended levels of N, P, and K. Since the current wheat varieties in the trials have a higher yield potential than the varieties used when the trials started, however, the

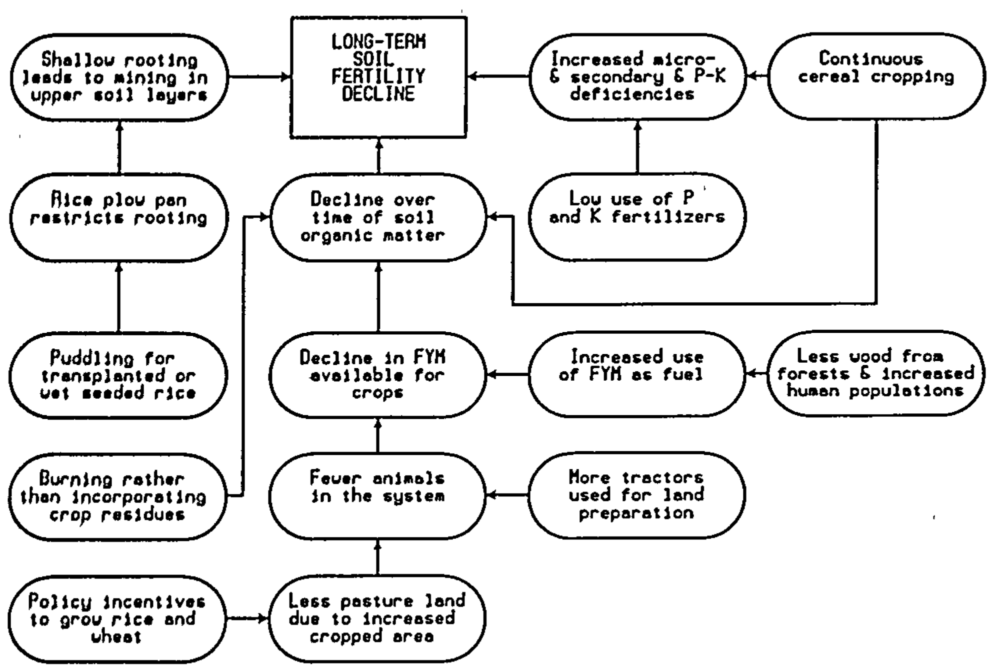

Fig. 1. Causes of long-term problem of declining soil fertility in the rice–wheat systems of South Asia.

finding that wheat yields remained constant over time may indicate a decline in productivity. Reasons for reduced rice and wheat yields are unclear, but may include diminishing soil organic matter or degraded soil physical properties. (See the unpublished report by Bhardwaj, V., Ram, V. and Tripathi, R. P., 'Report on long-term rice–wheat trial at Pantnagar, G.P. Pant University, Department of Soil Science, Pantnagar, India.) Data from solarization experiments in Nepal suggest that soil-borne microorganisms (possibly rice root nematodes in rice and foot rots in wheat) also may have influenced these declines.

At Faizabad and Pantnagar, the use of inorganic fertilizer on wheat and rice has risen substantially in the past decade. Some farmers claim more fertilizer is needed to maintain yields. Similarly, farmers who reported increasing or stable wheat yields in Jessore and Kushtia applied substantially higher rates of FYM than farmers who reported declining yields (Saunders, 1991). Data from an experiment near the Nepal site, which features a continuous rotation of rice–rice–wheat, show that over 14 years rice yields have declined for some treatments, especially those not receiving phosphorus. After five to seven years, the early rice crop in plots without phosphorus yielded nothing; the other rice crop and the wheat crop yielded very little. After 12 years, the three crops showed symptoms of potash deficiency. The FYM treatment (10 t/crop) was as stable as the recommended N-P-K treatment and resulted in increased total and available phosphate, organic carbon, total nitrogen, and available boron in the soil over time (Table 8).

Although farmers' perceptions of trends in rice and wheat yields varied, farmers commonly attributed yield increases to the introduction of new varieties, increased fertilizer application rates, new irrigation facilities, and improved crop management. All of these factors are likely to mask declines in total factor productivity.

The problem of soil nutrient mining needs to be defined and quantified further through analysis of information from long-term trials and long-term monitoring of farmers' fields. Long-term trials exist at Pantnagar, Rupandehi District, and Faizabad. A project for monitoring farmers' fields started in Rupandehi District in 1990. No long-term trials on the rice–wheat rotation have been established in Pakistan, and in Bangladesh one trial has only just started. Other research to improve nutrient use efficiency and nutrient cycling is presently underway at several locations (Table 9). Each national program must decide eventually whether to begin long-term trials (which are expensive) or to monitor farmers' fields (a less costly alternative). Whatever decision is made, useful data on sustainability will not be available for several years. The problem of nutrient depletion needs to be investigated by each national program and

TABLE 8
Characteristics of Soils after 30 Crops of Rice and Wheat, Rupandehi, Nepal

Characteristic	*0 N, 0 P, 0 K*	*N, P, K*[a]	*Farm yard manure*
pH (1:1 H_2O)	8·1	8·1	8·1
OC (%)	0·648	0·771	1·773
Total N (%)	0·071	0·088	0·167
Exchangeable Na (meq/100 g)	0·086	0·092	0·133
Exchangeable K (meq/100 g)	0·069	0·060	0·079
Exchangeable Mg (meq/100 g)	3·33	2·80	4·90
Exchangeable Ca (meq/100 g)	19·8	15·2	18·2
CEC	7·12	7·50	12·50
Total P (ppm)	168·0	248·0	403·0
Total Fe (%)	2·01	2·07	1·94
Total Mn (%)	153·0	135·0	153·0
Total Cu (ppm)	10·0	9·0	9·0
Olsen P (ppm)	nil	nil	16·0
Available Zn	nil	nil	nil
Available B	0·53	0·68	1·73

[a] Rate is 100 kg/ha N, 30 kg/ha P_2O_5, and 30 kg/ha K_2O for rice and wheat, as reported in Neue (1989, unpublished mimeo), Bhairahawa soils analysis (mimeo).

TABLE 9
Suggested Research on Long-Term Problems of Nutrient Mining and Build-up of Insects, Weeds, and Diseases

Problem	*Pantnagar*	*Faizabad*	*Rupandehi*
Nutrient mining			
Collate long-term data on yield declines	+	+	+
Long-term monitoring of farmers' fields	+	+	+
Cycling nutrients from deeper soil layers	+	–	–
Improved inorganic fertilizer use	–	–	+
Increasing organic matter or organic matter use efficiency			
legumes and green manures in rotation	+	+	+
residue management and organic fertilizers	+	+	+
improved FYM management	+	–	+
agroforestry to decrease FYM use as fuel	+	–	+
alternative fodder sources	–	–	+
Buildup of pests (insects, weeds, diseases)			
Further definition and assessment	+	+	+

by the international centers in order to develop an overall comparative analysis.

Insect and disease problems affecting rice are numerous: brown planthopper; rice bug; caseworm; leafminer (*Psuedonapomyza spicata*); rice hispa (*Dicladispa armigera*); yellow (*Scirpophaga incertulas*), darkheaded (*Chilo polychrysus*), and pink (*Sesamia inferens*) stemborers; bacterial leaf blight (*Xanthomonas campestris* pv. *oryzae*); false smut (*Ustilaginoidea virens*); sheath rot (*Acrocylindrium oryzae*); rice root nematode (*Hirschmaniella oryzae*); and bacterial leaf streak (*Xanthomonas campestris* pv. *oryzeola*). Problems of wheat include armyworm, termites, loose smut (*Ustilago tritici*), karnal bunt (*Tilletia indica*), leaf rust (*Puccinia recondita*), and *Helminthosporium* and *Alternaria* leaf blights. Leaf rust is less of a problem today because new wheat genotypes are resistant to the rust pathogen, but leaf blight causes more wheat yield losses in the rice–wheat system. Its prominence is probably related to continuous rice–wheat cultivation and the management of crop residues.

Weeds that may become significant problems include *Ischaemum rugosum* in rice and *Avena sativa, Convolvulus arvensis,* and *Cirsium arvense* in wheat (in addition to the weeds mentioned above).

Pests may be increasing in the rice–wheat system because continuous cultivation of the two crops extends the period in which suitable hosts are available. This may expand the numbers of rats, stemborers, fungal diseases, and (possibly) nematodes.

Many of the proposed 'solutions' to major rice–wheat problems could exacerbate pest-related problems. Weed seeds can be introduced into fields via FYM applications. Also, if reduced tillage is used between crops, populations of stemborers and fungal pathogens left in the rice stubble can increase. This possible problem should be explored in long-term tillage trials involving detailed counts of pests (including diseases) throughout the wheat and rice seasons.

Agroclimatic problems may also exacerbate pest problems. Excess soil moisture in wheat fields can lead to weaker plants, which are more vulnerable to pest damage. Insufficient soil moisture can increase the incidence of sheath blight, sheath rot, brown leaf spot, and blast on rice. As pest populations grow, increased pesticide application can reduce natural enemies; as less FYM is used, high rates of inorganic nitrogen can lead to more bacterial leaf blight, leaffolders, and planthoppers (Fig. 2).

Determining whether pest problems are increasing, and to what degree, will require long-term field monitoring, crop loss assessment, long-term trials, and ecological studies. Such research needs to be conducted by both national and international research centers to compare site data and determine overall system trends over time and space.

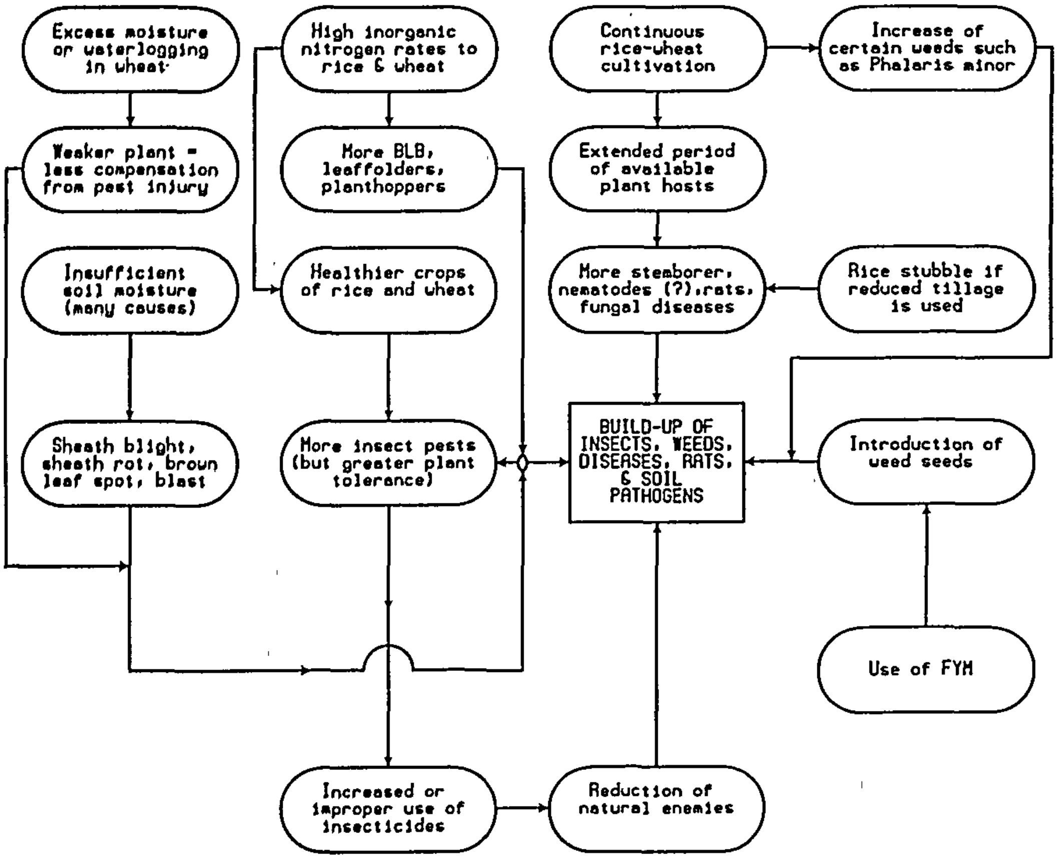

Fig. 2. Causes of the long-term promblem of pest build-up in the rice–wheat systems of South Asia.

In summary, problems affecting rice in the system resemble those affecting rice elsewhere, whereas wheat faces problems such as late sowing that can be traced largely to the preceding rice crop. The sustainability of the rice–wheat *system*, moreoever, may be threatened by soil nutrient depletion and pest buildup. Although wheat and rice yields have risen in most parts of Asia, increased fertilizer use, expansion of irrigation, and the introduction of improved germplasm may mask problems of land and water degradation. Rice–wheat research must continue to define and understand long-term trends, to seek ways of improving soil nutrient cycling and increasing organic matter in the system, and to diminish the negative effects of rice culture on wheat, while remaining aware of the many tradeoffs and drawbacks involved in potential 'solutions'.

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