The Rice-Wheat Pattern in the Nepal Terai: Issues in the Identification and Definition of Sustainability Problems

L. Harrington, P. Hobbs, T. Pokhrel, B. Sharma, S. Fujisaka, and C. Lightfoot

INTRODUCTION

The concept of “sustainability” is taking an increasingly central place in the activities—and reporting—of Farming Systems Research-Extension (FSRE) practitioners. In the recent literature, examples of sustainability problems have been reported with respect to farmers’ practices, the agricultural resource base, policies, and institutional innovations.

Many of these examples are fairly dramatic. For example, Fujisaka and Garrity (1988) describe the use of hedgerow technology to reduce soil erosion and improve cropping-pattern productivity (over the long term) in one site in northern Mindanao. In this example, damage from erosion was readily observable, and farmers were vocal in their concern about the problem. Similarly, Roche (1988) reports the following description of sustainability problems in Java. “Many of Java’s steep upland areas have been classified as land which has become so degraded that it is, or soon will be, unable to sustain even subsistence agriculture.”

1Paper presented at the Ninth Annual Farming Systems Research-Extension Symposium, University of Arkansas, Fayetteville, October 9-11, 1989. It is based on an earlier paper, The Rice-Wheat Cropping Pattern in the Nepal Terai: Farmers’ Practices and Problems and Needs for Future Research, Fujisaka and Harrington, eds. The opinions expressed are not necessarily those of the International Maize and Wheat Improvement Center (CIMMYT), the National Agricultural Research Services Center (NARSC), the National Wheat Development Program (NWDP), the International Rice Research Institute (IRRI), or the International Center for Living Aquatic Resources (ICLARM).

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When problems related to sustainability are fairly obvious, with dramatic and readily observable effects, questions of "problem definition" are likely to seem trivial. For example, when researchers are faced with increasingly severe and widespread resource degradation, they are unlikely to agonize over whether a sustainability problem really exists.

Not all problems of sustainability need be so dramatic, however. This paper is particularly concerned with sustainability problems that may not be immediately obvious, but that nonetheless can have important effects over the long term. Less obvious problems of sustainability can occur when changes in other factors mask or obscure a long-term decline in productivity. For example, when farmers use increasing levels of inputs but yields remain stagnant, the underlying long-term reduction in productivity may not be immediately apparent. Nonetheless, this long-term deterioration in productivity can seriously affect farmers' incomes.

The term "sustainability" has been defined in numerous ways. Without attempting to comment on the various alternatives, we will restrict our discussion to "sustainability problems" defined in terms of the longer-term productivity of farmers' resources, including the resource base.

In this paper, we argue that researchers have tended to overlook hidden problems of sustainability, and that these problems require relatively high investments in diagnostic activities. The objectives of this paper are to (1) discuss problem definition in the context of sustainability issues; (2) describe ongoing research in the Nepal Terai which includes an attempt to define sustainability problems; and (3) discuss further research that may be required to properly define sustainability problems for the Nepal study area.

DEFINING AND DIAGNOSING SUSTAINABILITY PROBLEMS

Problem Definition

There are numerous approaches to FSRE, each with a somewhat different vocabulary and suggested sequence of research steps. Many of the differences between these approaches can be explained in terms of the problem areas, the agroclimatic environment, and the mix of disciplines present during a formative period in which the particular FSRE approach was first developed. Despite differences, there is broad common ground between approaches, especially when it comes to the importance of diagnosis, or problem definition (Harrington, et al., 1989).

In principle, the definition of sustainability problems (defined here as longer-term productivity problems) differs little from the definition of near-term productivity problems. In both cases, researchers need to ascertain:

1. Whether the problem really exists. Many diagnostic activities produce hypotheses about possible problems that prove to be unfounded when further evidence is accumulated.
2. The likely benefits that could be earned by solving the problem. This requires some measurement of the productivity loss, broadly defined, associated with the problem, and the incidence and frequency of the problem (e.g., percent of farmers affected, percent of the farm affected, frequency of loss).
3. The causes of the problem which, in turn, tend to suggest alternative possible solutions, each with an associated level of research expenditure (Trip and Woolley, 1989).

Special Considerations in Defining Long-Term Productivity Problems

In practice, the definition of sustainability problems introduces several complications into the problem-definition process.

Confounding factors: In attempting to ascertain whether a sustainability problem exists, researchers may have to sort through several confounding factors. These are factors that tend to mask or obscure a long-term negative trend in the productivity of farmers' resources. Confounding factors can include the following:

1. Increased application levels of purchased inputs, for example, fertilizer. (Gradually increasing levels of fertilizer can maintain yields at a roughly stagnant level, obscuring the fact that yields would decline at constant input levels.)
2. Adoption of high-yielding varieties. (A change to a more productive variety can mask yield reductions that would otherwise be observed and, in addition, can actually hasten the longer-term decline in productivity if plant nutrients are extracted more rapidly, but not replaced.)
3. Changes at the margin in land quality. (Average regional yields of a crop or a cropping pattern will appear to increase if better-quality lands are gradually substituted for lower-quality lands. This will be true even if the productivity of any particular field—at constant levels of purchased inputs—is gradually declining.)
4. Expansion in irrigated area. (This is a specific example of changes in land quality, noted above.)

Time paths and discounting: In attempting to ascertain the likely benefits
of solving a particular long-term productivity problem, several more complications arise:

1. Assessments of productivity loss are no longer single-cycle "snapshot" estimates. Rather, the past over time of reductions in productivity (at constant input levels) needs to be estimated and compared to alternative paths.

2. Estimates of the incidence (number of farmers affected, area per farm, etc.) and frequency of the problem also need to be expressed in terms of a path over time.

3. Appropriate discounting measures need to be included, to estimate the present value of the productivity loss. Again, this present value can be compared to the present value of losses associated with alternative strategies.

Identifying causes and proposing solutions: Even when researchers are convinced that productivity, at constant input levels, is declining over time, considerable further work may be needed to pinpoint the reasons behind this decline. Hypotheses may include (but need not be restricted to) increasing scarcity of macronutrients or micronutrients; buildup of pests or diseases; buildup of problem weeds; deterioration in soil physical or chemical structure (including gradual salinization); reduced soil moisture-holding capacity; soil loss through erosion, etc.

It is not always easy to pinpoint which of these hypotheses is most relevant to field conditions in a given study area. The close technical identification of specific reasons for a long-term decline in productivity is likely to require a combination of systems, commodity and disciplinary expertise. "Diagnostic" activities for defining sustainability problems may be even more challenging, complex, time-consuming, and expensive than the ones commonly used to define near-term problems.

THE RICE-WHEAT PATTERN IN THE NEPAL TERAI:
RESULTS OF A DIAGNOSTIC SURVEY

Before continuing with the discussion of sustainability issues (i.e., the identification and definition of hidden sustainability problems), we will describe in some detail a joint MARSC-CIMMYT-IRRI project on the rice-wheat pattern in the Nepal Terai. Farm-survey activities, farmers' practices, system interactions, and near-term problems (along with their causes and some possible solutions) will be discussed. We realize that this interrupts to a certain extent the discussion on sustainability, but feel that many readers will welcome adequate background material on the study area. Readers preferring to maintain a relatively narrow focus on "sustainability" are invited to skim over the next few sections, up to the section titled The Rice-Wheat Pattern in the Nepal Terai: Problems and Causes—The Longer Term.

THE CIMMYT-IRRI-NARS RICE-WHEAT RESEARCH PROJECT

The rice-wheat cropping pattern is extremely important in South Asia. Wheat is grown after rice on approximately 8.7 million ha in the region, accounting for about 25 percent of the region's wheat production. Wheat yields are low (less than 2 t/ha) even where irrigation is available (Hobbs, Mann, and Butler, 1987).

The International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI) are developing, in partnership with interested National Agricultural Research Systems (NARS), a collaborative research program on the rice-wheat pattern in South Asia. The collaborative research program has four main objectives:

1. Conduct adaptive and applied research to define and solve major problems associated with the rice-wheat pattern in selected, defined study area. Problems may include near-term productivity issues and longer-term sustainability issues.

2. Conduct a comparative analysis (over countries) of problems affecting the rice-wheat pattern in South Asia and identify possible solutions for these problems, which are effective under a wide range of local circumstances.

3. Improve the understanding of CIMMYT, IRRI, and participating NARS on how to address problems of sustainability.

4. Strengthen IARC-NARS linkages.

As an initial step in this collaborative research program, scientists from CIMMYT and IRRI joined with researchers from the National Agricultural Research Services Center, Nepal, to study the rice-wheat pattern in Nepal's Terai. To begin, a diagnostic, exploratory survey was conducted in February 1989. The survey focused on farming systems in Rupandehi District, where...
the rice-wheat pattern is central to farmers' livelihoods.

Survey Objectives and Procedures

The diagnostic survey had three major objectives:

1. Understand local farming systems: the rice-wheat pattern, interactions between rice and wheat, and interactions between the rice-wheat subsystem and other subsystems.

2. Define near-term and longer-term problems, and understand their causes.

3. Identify further research needs: to improve the definition of poorly defined problems, to improve researchers' understanding of causes, and to identify possible solutions to major problems.

Survey participants were senior researchers from the fields of agronomy, anthropology, economics, extension, pathology, and plant breeding. Morning and early afternoon field interviews (conducted independently by each of three subgroups) were followed by structured discussions, attended by all participants. Semistructured guidelines rather than formal questionnaires were used to guide discussions with respondents. Using a sequential approach, these guidelines were redefined daily, after discussion of new information obtained and data gaps still existing. Respondents were selected from all parts of Rupandehi District and included small and large farmers, extension workers, merchants, and government officials.

Rupandehi District

This district is part of Nepal's Terai and is located 100-200 m above sea level (Figure 1). The Terai, a part of the Gangetic Plain, represents about 14 percent of Nepal's total land area and 42 percent of the country's cultivated land.

Rupandehi District has a subtropical climate highly influenced by the southwest monsoon. On average, total annual rainfall reaches around 1,600 mm and increases from south to north. More than 85 percent of the rain comes in the period from mid-June to the end of September. November and December are the driest months, and light precipitation may be expected in January and February. Mean temperatures are lowest (15°C) in January and highest (30°C) in May. There are occasional strong, hot, dry westerly windstorms in April and May (APROSC, 1986).

The population of the district was 380,000 in 1981, with a growth rate of 2.23 percent per year. There are about 83,000 ha of cultivable land, of which

Figure 1. Wheat Planting Date: Problems and Causes
some 28 percent receives some irrigation.

**Land and Soil Types, and Land Use**

Farmers were found to use land-type classes that corresponded closely to technical classifications (APROSC, 1986). Farmers' land-type classes, like the technical classifications, are based on interrelated variation in soil, topography, and hydrology.

Lower terraces (locally *khala*) are characterized by heavier soils and poor drainage, and are commonly used for the production of long-duration (usually photoperiod-sensitive), traditional rice cultivars. These lands are normally left fallow after rice. Middle terraces (*Oshakesa*) are characterized by lighter soils and fewer drainage problems. Common cropping patterns on middle terraces include medium-duration rice varieties followed by wheat, wheat mixed with mustard, or other winter crops. Upper terraces (*danda*) are well-drained and drought-prone, and are planted to shorter-duration rice followed by wheat, various wheat-based crop mixtures, or winter vegetables.

**Rice-Crop Management for Middle and Upper Terraces**

On upper and middle terraces, rice is grown as a first crop, before the second crop of wheat. This section describes farmers' management practices for this first rice crop.

**Seedbeds and direct seeding:** Farmers prepare and sow seedbeds at the end of June. Transplanting in irrigated areas is usually finished within 30 to 45 days after seeding. Farmers in rainfed areas do not transplant until after the rains have started. As a rule, farmers avoid transplanting seedlings more than 60 days old. (Late transplanting, given the varieties commonly used by farmers, was reported to cause reductions in rice yields.) When rains are delayed, farmers may use direct seeding. This is more common in the upper terraces.

**Pests and diseases:** Farmers identified ricebug, armyworm, and stemborer as pests of increasing severity, and blight and blast as important diseases. Rats are a serious problem in the field and in storage (particularly in stacked rice, before threshing). Rats are also responsible for damage to bunds and irrigation infrastructure. Farmers reported using few control measures for insects, diseases, or rats.

Soil and root samples collected by the team's nematologist contained from 100 to 1,000 *Hirschmanniella* (cf. *oryzae*), the rice-root nematode, individuals per liter of soil in all samples. This parasitic nematode appears to be present throughout the district. Farmers take no control measures.

**Soil-fertility management:** Farmyard manure (FYM) is used in rice seedbeds and is occasionally applied in small quantities to rice fields prior to land preparation. Some farmers reported declining rice productivity, possibly due to low and declining FYM use. Declining yields were also said to be characteristic of fields with a longer history of intensified cropping.

Farmers using inorganic fertilizers reported applying 50-100 kg/ha of compound fertilizer (usually 20-20-0) at planting and 30-50 kg/ha urea as a topdress. This is equivalent to around 25-45 kg/ha of nitrogen and 10-20 kg/ha of phosphate (below recommended levels). Direct-seeded rice was said to usually receive only a urea topdress. Several farmers identified zinc deficiency as a problem, with Saryu-49 said to be particularly sensitive. Good sources of zinc fertilizer are not available.

**Harvest and postharvest:** Rice is hand harvested and is usually stacked (i.e., threshing is postponed) in order to free farmers' labor for wheat land preparation. Despite this practice, land preparation for wheat can still be delayed by a late rice harvest (or a need to further field dry rice that is too wet to stack). Farmers report having few rice-seed storage problems, as seed storage occurs during the cool, dry season.

**Wheat-Crop Management for Middle and Upper Terraces**

**Tillage:** Farmers usually plow four times and plank twice, with the first plowing requiring relatively more time. More plowings are usually used for heavier soils. In rain-fed areas where moisture is limited, farmers may reduce tillage operations or wait for the rains. Turnaround time from rice harvest to wheat planting requires around 15 to 35 days (mostly for plowing and planking), given the usual conditions of unfavorable soil moisture and soil physical condition. Farmers' practices, as described above, may result in over-tillage with detrimental effects on soil structure.

**Timing and method of planting, seed management, plant stand:** Most farmers broadcast seed into plowed soil, then cover the seed by plowing once again, and planking. Few farmers use line sowing and no farmers were found using seed drills. Seed rates vary from 120 to 180 kg/ha, with an average of around 150 kg/ha (compared to the recommended seed rate of 120 kg/ha).

Farmers' stored seed often suffers from the effects of pests and excess moisture. Farmers are reluctant to buy seed from the government because of the high cost (around Rp. 8 [US$.46] per kg) and relatively poor seed quality. If farmers' own stored seed is badly damaged, replacement seed (usually of
Indian origin, and composed of a mixture of varieties) is purchased from the market.

Visual observation of numerous fields suggested that only 15 to 20 percent of fields were planted during the optimum period of mid-to-late November. Around two-thirds of the fields were planted somewhat late (during the first two weeks of December) and the remaining 20 percent after mid-December. Plant stands were observed to be poor (fewer than 200 plants per m²) in about 20 to 25 percent of the fields; fairly in 60 to 65 percent of the fields; and good (more than 300 plants per m²) in the remaining 10 percent of the field.

Variety: Major wheat varieties used by farmers are RR21 and UP262. Several newly released varieties are gaining popularity (e.g., Siddartha, Vinayak).

Pests, diseases, and weeds: Insect pests are a major problem for stored wheat seed, but not for the crop in the field. Rats are a field and storage problem, and farmers have few rat control measures. Helminthosporium blight often causes significant yield losses. In addition, experimental evidence suggests that soil fungi and/or nematodes may be causing yield losses. Although the rice root nematode Hirschmanniella (cf. oryzae) was present in all soil samples taken, its effect on wheat yields is not known.

Some weeds (especially broadleaf leguminous types) were observed in farmers' wheat fields, but the effect of these weeds on wheat yields is unknown. Farmers cut and carry weeds for fodder, as needed. Weeds remaining in the field at harvest are cut and mixed with the straw for fodder. Some weeds (e.g., Phalaris minor and Cirsium arvense) seem to be increasing and may become problems as land use is intensified.

Water management: Wheat is grown as an irrigated, partially irrigated, and rain-fed crop, with the proportion of irrigated wheat increasing over time. Partially irrigated wheat usually receives only one irrigation. Fully irrigated wheat is irrigated two to three times, with the first irrigation within a month of emergence, and the second at flowering.

In the middle terraces, especially in fields with heavier soils, water may stand in the field (after an irrigation) for more than a day. Waterlogged patches also occur in poorly leveled fields. The farmers' practice of transferring water from one field to the next (a practice borrowed from rice cultivation) can also contribute to waterlogging.

Soil-fertility management: Some (but not all) farmers reported using inorganic fertilizers on wheat, usually a compound fertilizer (50-100 kg/ha of 20-20-0) at planting, and urea (30-75 kg/ha) as a topdress at first irrigation. Total application of nutrients, then, is on the order of 25 to 50 kg/ha of nitrogen and 10 to 20 kg/ha of phosphate (below recommended levels). Higher doses are used in irrigated areas. Few farmers apply potash.

Farmers reported using most of their FYM as fuel. FYM remaining after fuel needs are met is normally reserved for rice nurseries and vegetable fields. Usually, wheat fields are not regularly fertilized with FYM.

Harvest and postharvest: Wheat is hand harvested. Many farmers reported that the onset of hot, dry winds from the west tended to curtail the crop season, often affecting grain filling. Other farmers reported that the harvest (i.e., harvesting before the crop is well-dried in the field) to avoid premonsoon storm damage. These two weather-related problems seem inconsistent and are not yet well understood. Thresholding is largely by bullock trampling, although the use of small power-threshers is increasing. Storage losses due to monsoon weather and insect pests were not measured, but are probably significant.

Mixed cropping: It was observed that farmers commonly mix mustard (Brassica spp.) with wheat. Crop mixtures are more widespread in rain-fed and partially irrigated areas. Some farmers reported that they would shift to pure wheat cropping if irrigation were assured. Farmers normally do not plant mustard alone, apparently because of problems with aphids.

System Interactions: Interactions between Rice and Wheat

Rice-harvest date and wheat-planting date: A major source of interactions between rice and wheat lies in the competition between these two crops for the farmers' land and labor resources during the rice-harvest/wheat-planting period.

Experimental evidence suggests that mid-to-late November is optimum for wheat planting, with later dates resulting in reduced yields. Farmers report aiming to prepare and sow wheat fields as soon as possible after the rice harvest in October or November. Delays in rice harvesting can delay wheat planting. At first, survey participants hypothesized that delays in rice harvesting might be due to late rice transplanting, in turn due to late nursery establishment and/or late arrival of the rains. Farmers, however, reported sowing rice seedbeds in June (with irrigation if necessary). They also reported avoiding the transplanting of older seedlings (over 60 days old). When the rains are late, farmers direct seed a considerable proportion of upper and middle terrace rice areas. Changes in farmers' rice planting practices, then, are unlikely to contribute to more timely rice harvest and wheat planting.

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Earlier maturing rice varieties can also lead to an earlier rice harvest, thus facilitating early wheat sowing. However, farmers on middle and upper terraces are already using shorter maturity varieties (compared to farmers on lower terraces). High yield is associated with longer maturity, so these farmers are already sacrificing a certain amount of rice yield.

Farmers are busiest (labor is most scarce) in November and December when rice is harvested and wheat fields are prepared and sown. Farmers save some time during this period by delaying rice threshing until after the wheat is sown: they stack the rice for later threshing. Rice storage losses to rats are a consequence (farmers estimated an 8 to 15 percent loss).

The farmers' practices described above (timely rice transplanting; direct seeding of rice; use of shorter-duration varieties; delayed rice threshing) all aim to reduce the competition for land and labor between rice and wheat.

**Effect of paddy soils on wheat:** The subsurface pan formed by the puddling of soils for rice cultivation, combined with farmers' wheat land-preparation methods (intensive, but shallow tillage), seem to reduce wheat productivity.

The subsurface pan apparently contributes to two separate problems related to moisture: it restricts water percolation (and therefore contributes to waterlogging after irrigation); and it reduces soil moisture-holding capacity (and therefore contributes to late-season moisture stress). The subsurface pan also restricts root growth to a narrow soil layer, contributing to the depletion of plant nutrients in that layer. The practice of puddling destroys soil structure, which is difficult to reestablish. Effects on wheat of soil chemical and physical changes due to alternating flooded and dry conditions are not yet well understood.

The problems noted above are specific to soils found after the production of puddled rice. Dry, direct-seeded rice does not require puddling and seems to cause fewer problems for subsequent upland crops such as wheat.

**Food security for resource-poor farmers:** Wheat production appears to play an important food security role for low-income farm households. Rice from middle and upper terraces becomes available in October, and traditional rice from lower terraces in December. Wheat becomes available in March, when rice begins to get scarce. Although rice is the main staple, wheat is widely consumed during the months immediately after its harvest.

**Fodder:** Rice straw is the major fodder source, and taller, long-duration rice cultivars (grown on the lower khala terraces) provide the greatest proportion of straw. Secondary fodder sources include wheat straw, grazing, and cut grasses and weeds. Seasonally, lower terraces left fallow provide pastureage for grazing after the rice harvest in November but are depleted by about March. Wheat straw (usually mixed with rice straw) is available between March and July. Some farmers report having enough rice straw to last all year, though many do not. Supplies of rice straw become available in October and begin to run out by February or March. Farmers agree that fodder is particularly scarce from July through September. Many farmers feel that fodder is increasingly scarce all year and, as a consequence, herd sizes are declining.

**Fuel:** Given the lack of accessible forest areas in this district, firewood has lost much of its importance as a source of fuel. Dried dung cakes now provide most local fuel needs. These dung cakes may account for up to 75 percent of the FYM produced by a farm household's animal herd.

**FYM as fertilizer:** Increasingly, FYM is used primarily as fuel, but some is still available for use as fertilizer. Farmers report the following priorities for FYM as fertilizer: rice seedbeds; cash crops on lighter danda soils (especially on fields close to the farm house); fields where declining productivity has been noted; and other rice or wheat fields.

**THE RICE-WHEAT PATTERN IN THE NEPAL TERAI: PROBLEMS AND CAUSES—THE NEAR TERM**

A major objective of the diagnostic survey was to develop hypotheses for problems affecting the rice-wheat pattern. A "problem" in this context is defined to include the following: (1) factors that directly reduce yields; (2) inefficient use of inputs, regardless of the effect on yields; (3) inefficient cropping patterns or enterprise selection; (4) factors affecting the sustainability of rice and wheat productivity.

The first three classes of "problems" are near-term in nature, and can be
assessed within the time frame of a crop cycle (a few months) or a cropping pattern (one year). These near-term problems and their corresponding causes are briefly discussed in this section and are listed in Table 1. (For a more thorough discussion of these near-term problems, including causes and suggested possible solutions, see Fujisaka and Harrington, eds., 1989).

The last class of problem (factors affecting sustainability) is long-term in nature and will be discussed separately.

Problem 1: Late Planting Reduces Wheat Yields

Late wheat planting appears to be a problem in all land-soil types in which wheat is grown, and especially in the middle terraces. As noted earlier, visual observation of numerous fields suggested that only 15 to 20 percent of fields were planted during the optimum period of mid-to-late November.

Problem 2: Early Season Waterlogging Reduces Wheat Yields

This problem, which is most important in irrigated middle terraces with heavier soils, appears to have two interrelated causes: the subsurface pan left in the soil by puddled rice culture (and related problems with soil structure),

Table 1. Preliminary List of Problems: Rice-Wheat Pattern, Rupandehi District

<table>
<thead>
<tr>
<th>Near-Term Problems:</th>
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<tbody>
<tr>
<td>WHEAT</td>
</tr>
<tr>
<td>1. Late planting</td>
</tr>
<tr>
<td>2. Early season waterlogging</td>
</tr>
<tr>
<td>3. Inadequate plant stand</td>
</tr>
<tr>
<td>4. Late season moisture stress</td>
</tr>
<tr>
<td>5. Nutrient deficiencies (especially N and P)</td>
</tr>
<tr>
<td>6. Farmers' wheat varieties are less productive than alternatives</td>
</tr>
<tr>
<td>RICE</td>
</tr>
<tr>
<td>7. Pests (stemborer, planthoppers) and disease (blast)</td>
</tr>
<tr>
<td>8. Mid-season moisture stress</td>
</tr>
<tr>
<td>9. Nutrient deficiencies (especially N, P, and Zn)</td>
</tr>
<tr>
<td>10. Weed competition (direct-seeded rice)</td>
</tr>
<tr>
<td>Longer-Term Problems:</td>
</tr>
<tr>
<td>WHEAT AND RICE</td>
</tr>
<tr>
<td>1. Nutrient deficiencies will increasingly limit the yields of both wheat and rice</td>
</tr>
<tr>
<td>2. Pests and diseases will increasingly limit the yields of both rice and wheat</td>
</tr>
</tbody>
</table>

and farmers' irrigation practices (and related problems with irrigation and drainage infrastructure and water control) (Figure 2).

In most irrigation systems, farmers are compelled (by poor water-control structures) to water their wheat crop as if it were rice—by moving water from field to field. When soils are heavy and when a plow pan is left over from the previous rice crop, the normal result is water standing in the field, often for more than 24 hours. This can directly reduce wheat yields, as well as affecting plant stands.

![Diagram](image-url)
Problem 3: Inadequate Plant Stands Reduce Wheat Yields

As noted earlier, researchers inspected numerous wheat fields during the diagnostic survey and found that plant stands were usually poor to fair. Around a fourth of the fields were observed to have poor stands (less than 200 plants/m²), with over half having only fair stands (200 to 300 plants/m²). The stand problem was especially acute on rain-fed middle terraces with heavier soils. There appear to be a number of causes for poor stands, including poor tilth (combined with broadcast seeding), poor seed quality, and waterlogging (Figure 3).

Problem 4: Late-Season Moisture Stress Reduces Wheat Yields

This problem occurs on all land-soil types in which wheat is produced. The average productivity loss and the probability of occurrence, however, are not well known at this time.

Four major causes of late-season moisture stress were tentatively identified: (1) late planting, (2) hot, dry winds in February or March that curtail grain filling, (3) avoidance of late-season irrigation (this tends to exacerbate lodging problems associated with the strong March winds), and (4) reduced soil moisture-holding capacity due to the subsurface pan.

Problem 5: Nutrient Deficiencies Restrict Wheat Yields

Nutrient deficiencies (especially of nitrogen and phosphorous) are suspected to reduce the yields of both rice and wheat. To avoid repetition, the discussion on the near-term problem of nutrient deficiency is combined with the section on the longer-term problem of gradually declining soil fertility.

Problem 6: Farmers' Wheat Varieties Are Less Productive than Alternative Varieties

Most farmers currently grow one of two varieties: RR21 or UP262. Several newly released varieties (Siddartha, Vinayak) are only slowly beginning to be used by farmers. There seem to be two interrelated causes for the slow adoption of newly released varieties: (1) it is difficult for farmers to obtain seed of new varieties, and (2) many farmers report not being well acquainted with the new varieties (understandably, given the difficulty they have in getting seed).

Problems 7 through 10: Problems Associated with Rice (pests and diseases, mid-season moisture stress, nutrient deficiencies, weed competition in direct-seeded rice)

Less diagnosis was conducted (and fewer problems identified) for the rice crop within the rice-wheat pattern. This was because the diagnostic survey being reported was conducted during the wheat season. (Another survey was conducted during the rice crop season in September 1989, but the results of this survey are not yet available).

In addition, two problems associated with rice (pests and diseases, nutrient deficiencies) have both a near-term and a longer-term dimension. To avoid repetition, the discussions of near- and longer-term issues are combined in the section on long-term problems.
Near-Term Problems: A Summary

It should be clear from the preceding sections that there are a number of serious and complex near-term productivity problems affecting wheat in the study area that, moreover, interact with each other. The diagnostic survey made considerable progress in defining these problems. Still, the problem-definition process is not yet finished.

Productivity loss: Survey results, combined with other sources of data (experimental results, the body of agronomic knowledge available from other study areas) enabled researchers to make some judgments about the productivity loss associated with each problem (Table 2). These estimates are still exceedingly imprecise, however. Further work (involving both surveys and on-farm experiments) will be needed to improve estimates of productivity loss (as well as to assess solutions).

Incidence and frequency: Survey participants gained some feeling for the geographical incidence of many of the problems (Table 2). For example, waterlogging was found to be concentrated on irrigated middle terraces, with heavier soils. Nonetheless, researchers still have only a very imprecise understanding of the geographical distribution of each problem, and the proportion of farmers in the study area (and the area per farm) affected. Closely focused, formal surveys using random sampling will be needed to quantify these variables.

Table 2. Near-Term Problems: A Summary (Wheat Only)

<table>
<thead>
<tr>
<th>Problem</th>
<th>Yield loss of farmers</th>
<th>Location</th>
<th>Percentage</th>
</tr>
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<tbody>
<tr>
<td>Late planting</td>
<td>Moderate</td>
<td>Most land types, especially middle terraces</td>
<td>80 (?)</td>
</tr>
<tr>
<td>Waterlogging</td>
<td>Serious</td>
<td>Irrigated middle terraces, with heavier soils</td>
<td>35 (?)</td>
</tr>
<tr>
<td>Inadequate plant stand</td>
<td>Serious</td>
<td>Middle terraces, with heavier soils</td>
<td>50 (?)</td>
</tr>
<tr>
<td>Late-season moisture stress</td>
<td>Serious</td>
<td>Upper terraces, with lighter soils</td>
<td>50 (?)</td>
</tr>
<tr>
<td>Nutrient deficiencies</td>
<td>Moderate</td>
<td>Most land types, especially upper terraces</td>
<td>80 (?)</td>
</tr>
<tr>
<td>Variety</td>
<td>Moderate</td>
<td>Most land types</td>
<td>80 (?)</td>
</tr>
</tbody>
</table>

Is There a Sustainability Problem?

Some doubt remains as to whether a sustainability problem even exists with regard to the rice-wheat pattern in the Nepal Terai. What evidence is there to suggest that rice-wheat farmers face a prospect of slowly declining productivity?

Farmer opinion: Farmer opinion on the subject of productivity trends is somewhat divided. These differences of opinion, however, tend to fall out as follows:

1. Type A farmers: These farmers claim that yields of both rice and wheat are increasing over time, because of expanded irrigation area, increased use of high-yielding rice and wheat varieties, and increased use of chemical fertilizer (on irrigated land). However, Type A farmers tend to have only recently benefited from the installation of irrigation and tend to have had only brief experience with the rice-wheat pattern (often less than five years).

2. Type B farmers: These are farmers growing the rice-wheat pattern in rain-fed upland (ex-forest) areas, usually on light-textured danda soils. They tend to use few if any inputs, including FYM. Farmers here engage in classical "soil mining" and recognize that productivity is declining.

3. Type C farmers: These are farmers with longer experience (more than five years) with the rice-wheat pattern in irrigated areas. These farmers claim that, with the introduction of the intensified (rice-wheat) pattern, yields of both rice and wheat initially increased, but then began to decline. Some farmers have observed a gradual decline in productivity despite the application of (what they consider) reasonable levels of inputs.

Further evidence from the diagnostic survey on questions of sustainability is provided in the section titled Long-term Problem 1.

Time series data: Time series data on average regional yields for rice and wheat are considered to be unreliable. In any event, these data are more likely
Experimental data: There are some experimental data that suggest that the productivity of the rice-wheat pattern is likely to decline over time, given farmers' current management practices. Here are a few examples.

A long-term fertilizer trial was conducted for seven years under the auspices of the National Wheat Development Program, on their experiment station in the Rupandehi District study area. This trial was composed of nine treatments (involving different combinations of N, P, K, FYM, and stubble management) (Table 3). Each treatment was superimposed on the same plots for three crops per year. (Researchers used a rice-rice-wheat pattern for this experiment, more intensive than the farmers' practice, which may tend to exaggerate the observed decline in productivity. Similarly, the trial was conducted on the khala land type usually reserved for lowland rice, thus raising questions about the representativeness of the trial.)

The data from this trial indicate that wheat yields have been fairly stable for all treatments over the seven-year period, but that rice yields—and therefore, total annual grain yields—have declined drastically for most treatments (Regmi, 1986). The proper presentation of this data set would require a separate paper. However, for present purposes, a simple comparison between yields for the early years (the average of years 1 and 2), versus the later years (the average of years 6 and 7) is sufficient to illustrate the point. This comparison is made for the first rice crop and the wheat crop (Table 4). While these results are presented for illustration only, they support the hypothesis that long-term declines in productivity are not unlikely.

There are other sources of evidence. Hobbs (1987) reports that data from the All-India Long-term Soil Fertility Trial series show depletion of P and Zn in rice-wheat areas. In other areas, deficiencies of K and B, and problems with pH were observed.

Comment: In summary, there is no single data set that convincingly and unambiguously confirms that farmers are facing a long-term decline in productivity in the rice-wheat pattern. Rather, there are indications from various sources that the pattern, as currently managed, may not be sustainable. The indications seem strong enough, however, and the sources sufficiently consistent, to be cause for alarm.

The discussion of long-term issues has so far focused on soil fertility. Additional evidence on nutrient depletion, and pest and disease buildup will be presented in the next sections.

Table 4. Long-Term Fertilizer Trial—Partial Results Grain Yield:
First Rice Crop, Wheat Crop (t/ha)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Yields</th>
<th>Average Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Years 1 and 2</td>
<td>Years 6 and 7</td>
</tr>
<tr>
<td></td>
<td>Rice Wheat</td>
<td>Rice Wheat</td>
</tr>
<tr>
<td>1</td>
<td>2.5 0.8</td>
<td>0.6 1.1</td>
</tr>
<tr>
<td>2</td>
<td>3.8 1.0</td>
<td>1.1 1.2</td>
</tr>
<tr>
<td>3</td>
<td>3.8 1.8</td>
<td>2.3 2.1</td>
</tr>
<tr>
<td>4</td>
<td>3.9 1.2</td>
<td>1.0 1.3</td>
</tr>
<tr>
<td>5</td>
<td>4.0 2.1</td>
<td>2.8 2.5</td>
</tr>
<tr>
<td>6</td>
<td>3.7 1.9</td>
<td>1.9 2.4</td>
</tr>
<tr>
<td>7</td>
<td>3.2 1.0</td>
<td>0.7 1.0</td>
</tr>
<tr>
<td>8</td>
<td>3.3 1.3</td>
<td>2.2 2.3</td>
</tr>
<tr>
<td>9</td>
<td>2.9 1.9</td>
<td>2.3 2.2</td>
</tr>
</tbody>
</table>

Source: Based on Regmi (1986), referred to in a personal communication by D. Saunders.
Long-Term Problem 1: Nutrient Deficiencies Will Increasingly Limit the Yields of Both Rice and Wheat

Hypotheses: Field observations made during the diagnostic survey suggested that nutrient deficiencies were already restricting wheat yields, especially on lighter soils in the upper terraces (Type B farmers). This is not surprising, given these farmers' soil-fertility management practices. Researchers hypothesized (independently of the long-term trial data presented in the last section) that the preceding rice crop is probably subject to similar nutrient stresses. Further diagnostic work is needed, however, to clarify the relative importance of different nutrients and identify interactions among nutrients. (Note that nutrient deficiency problems may differ between farmer Types A, B, and C.)

This problem of nutrient deficiencies seems likely to get worse over time. Those farmers with longer experience with intensified cropping patterns (Type C farmers) indicated that yields of both rice and wheat are lower now than when intensified cropping began. Hypothesized causes of nutrient deficiencies are listed below. Note that many of these causes are likely to have cumulative effects over time.

1. The rice-wheat cropping pattern tends to exhaust soil nutrients, compared to the earlier cropping pattern of rice-fallow; as more fields are shifted to this pattern, nutrient deficiencies are likely to become more common.
2. The subsurface pan (left by puddled rice culture) restricts the rooting zone of wheat as well as rice, thus upper soil layers are being mineralized of plant nutrients.
3. Farmers apply only low levels of inorganic fertilizer to both crops.
4. As FYM supplies decline, and as FYM is increasingly used for fuel, farmers are reducing to negligible levels the application of FYM to rice and wheat; many rice and wheat fields receive no FYM at all.
5. Crop residues and weeds are fed to livestock rather than incorporated into the soil.

Improving problem definition regarding nutrient deficiencies: Future diagnostic research on the long-term problems posed by nutrient deficiencies is likely to focus on three interrelated questions: (1) Which nutrients are limiting? (2) How does productivity decline over time as a consequence of nutrient deficiencies? (3) What is the distribution of nutrient deficiencies in the study area? (This question of geographical incidence is likely to be strongly affected by the farmer types noted earlier.)
Current thinking is that, in the Rupandehi study area, P is usually the limiting factor for wheat, and both P and Zn for rice—especially in the upper terraces. These thoughts are suggested by background knowledge of rice and wheat agronomy, in combination with data from one on-station experiment in the study area, and a series of experiments in similar areas of India. Clearly, further research is needed in Rupandehi District itself to clearly identify the order in which nutrients become deficient, the effects of these deficiencies over time, and their distribution within the district.

Several sources of data can be used to address these questions. The use of long-term trials (on-station and/or on-farm) is one obvious approach. Another approach would involve the use of nurseries of indicator species capable of flagging well-defined micronutrient deficiencies under farmers’ conditions (D. Saunders, personal communication). Yet another approach would involve monitoring a panel of farmers over time, to track rice and wheat yields and relate these to farmers’ soil-fertility management practices, including FYM supplies and management. In addition, single-visit surveys using random sampling may be needed (in conjunction with soils information) to test some of the hypotheses on the causes of the soil fertility problem.

It should be clear however, that this three-dimensional uncertainty (which nutrient? what time path? what geographical distribution?) tremendously complicates problem definition.

Alternative solutions for the nutrient-deficiency problem: Although there appears to be no simple solution to nutrient deficiency problems, researchers might consider the following themes (suggested by the hypothesized causes of the problem):

1. Realistic and profitable doses (and forms of application) of inorganic fertilizer, possibly including micronutrients (e.g., zinc for rice).
2. Improved FYM management and techniques to combine FYM and inorganic fertilizer, to increase fertilizer efficiency.
3. Development of alternative sources of fodder, to allow an increase in animal herd size, increased production of FYM, and the incorporation of more FYM and crop residues back into the soil (e.g., fitting multipurpose [grain-fodder-green manure] legumes into the system).
4. Development of alternative fuel sources, to enable farmers to use FYM as fertilizer instead of fuel (e.g., agroforestry research to test alternative tree species as sources of fuel and fodder, etc.).

A suitable research agenda will likely make use of various sources of information, including conventional researcher-managed, on-farm research trials; farmer-participatory research (especially with respect to agroforestry and green legume research); researcher and/or farmer-managed, long-term trials, and monitoring of a farmer panel (required to measure the time path of benefits associated with different interventions); exhaustive analysis of past and present data sets (given the expense of setting up new sets of trials).

Long-Term Problem 2: Pests and Diseases Will Increasingly Reduce Rice and Wheat Yields

There is evidence that a number of pests and diseases reduce wheat yields in the study area. These include *Helminthosporium* blight, nematodes, soil fungus, rats, etc. With respect to rice, farmers report problems with blast, rice bug, stemborer, and rats. The incidence, frequency, and yield loss associated with each of these is not yet well understood. Similarly, there is little evidence on the time path of productivity changes (are these problems getting worse over time?).

Evidence on pests and diseases includes the following:

• Solarization trials conducted at the NWDP experiment station at Bhairahawa indicate that unidentified biotic factors have a strong negative effect on wheat yields.

• The rice root nematode (*Hirschmaniella* sp.) was found in all soil samples obtained from farmers’ fields in the study area during the diagnostic survey. However, it is as yet unknown whether these cause any yield loss for wheat.

• Evidence from similar rice-wheat areas of Bangladesh suggest that biotic factors are reducing wheat emergence and plant stand (D. Saunders, personal communication, reported by P. Hobbs).

Though there is little evidence at this time to support it, there is widespread concern that these problems may become more severe as time passes. This is simply because the rice-wheat pattern (which is relatively new to the study area, and still expanding in size) seems more likely to allow a buildup of pests and diseases than the earlier rice-fallow pattern.

For biotic factors, problem definition remains at an early stage. As noted, research is needed to determine which pests and diseases (if any) are increasing in severity or frequency. Long-term trials and monitoring may be needed to trace out time paths, as well as specialized surveys to measure the incidence of problems in the study area. In addition, on-station research and laboratory
testing, conducted by trained disciplinary specialists, are likely to be needed.

Discussion and Conclusions

The rice-wheat pattern as cultivated in Rupandehi District of the Nepal Terai suffers from a number of problems, many of them near-term in nature. For example, problems associated with wheat stand establishment, water-logging, planting date, etc., appear to have major effects on wheat productivity.

The rice-wheat pattern also appears to suffer from problems of sustainability—problems, moreover, that are not immediately obvious. Available secondary data do not clearly indicate declining productivity of rice and wheat over time. Similarly, farmer opinion is mixed, with some farmers reporting that yields are declining, while other farmers report that yields are stable or increasing.

Other sources of information, however, do suggest that rice and wheat productivity are declining. These sources include:

- Stratification of farmers into farmer types: the only farmers reporting increasing yields are those with a brief experience with intensified cropping. Farmers with more experience tend to report declining yields.
- Results from a long-term, on-station fertilizer trial, along with reports of similar results from similar rice-wheat areas of India, that indicate rapid declines in rice yields over a seven-year period under a wide array of soil-fertility management strategies.
- A marked trend among farmers toward the reduction of FYM applications to rice and wheat, in response to declining herd size (hence, declining FYM availability) and increased use of FYM for fuel.
- On-station research results suggesting that unknown biotic factors (nematodes? root rots?) have a strong effect on yields, together with the hypothesis that these biotic factors may tend to become more important in the intensified rice-wheat pattern, as compared to the earlier rice-fallow pattern.

Much work on problem definition remains, however. The time path of productivity loss needs to be traced out; the changing incidence of each problem needs to be identified; and hypothesized problem-cause relationships need to be tested. All of these are challenging, complex, expensive, and time-consuming tasks. Moreover, these tasks will require the services of commodity and disciplinary scientists, as well as dedicated “systems researchers.”

In the end, researchers will probably have to assemble the best estimates of yield response and productivity loss from the different available data sources, then construct a synthetic time path of productivity change for each of the different soil-fertility management strategies (including the farmers’ practice), and calculate the net present values associated with each of these strategies. Discounting need not be deferred until the end of the long-term trials; as data accumulates, it can be fed into successive approximations of the complete time path associated with each management strategy.

The sustainability problems discussed in this paper may not be as dramatic as those discussed by some other researchers, e.g., dealing with extensive deforestation or highly visible soil erosion. However, the very “nonobviousness” of these problems may tend to delay their definition and obscure their importance, with ultimately disastrous effects on productivity and farmers’ livelihoods.

REFERENCES


