Annual Report

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Sustainability of Post-Green Revolution Agriculture: The Rice-Wheat Cropping System of South Asia

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by

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EXECUTIVE SUMMARY

It is widely recognized that productivity of the rice-wheat cropping system is stagnating and possibly declining. The reason(s) for this is (are) not well understood, although various soil physical, chemical and biological constraints to productivity have been identified. Our research has led us to the conclusion that root health is the major factor constraining crop yields and that rice is more vulnerable that wheat. Soil-borne pathogens and parasitic nematodes create major problems with respect to crop establishment, growth and yield. Poor root health increases susceptibility to abiotic stresses, such as drought, and reduces access to nutrients.

Root health has been little studied in the rice-wheat system, which highlights a deficiency in the conventional disciplinary approach of agricultural scientists and institutions to problem solving. Although there are undoubtedly several organisms damaging roots, we have focussed on the impact of the root knot nematode, *Meloidogne graminicola* on rice. We have learned that:

- Infection of rice roots with *M. graminicola* commonly occurs in rice nurseries.
- *M. graminicola* causes yield reductions of at least 1-2 t/ha in NW Bangladesh.
- In the absence of host plants, *M. graminicola* survives and maintains “pathogenicity” better in flooded than in drained soil.
- Both rice and wheat are excellent hosts for *M. graminicola*, but some crops that substitute in the rotation are not (sesame, jute), suggesting a possible approach to controlling the nematode.

We have used solarization of rice nursery soils, sometimes coupled with seed treatment with a fungicide, as one strategy to address the root health problem. We have previously shown, in limited studies, that ***healthy seedlings*** produced by this technique can increase rice yields up to 45%. In year 5, we extended the soil solarization technology to a group of 25 farmers in NW Bangladesh using a participatory approach. The mean rice yield with ***healthy seedlings*** was 5.2 t/ha compared to 4.0 t/ha with seedlings from non-solarized nurseries, and 16 of the 25 farmers achieved a yield increase between 30-40%.

A second strategy to improve root health of both rice and wheat is through the use of micronutrient enriched seed. Several micronutrients (Mn, Zn, Cu, B) are known to increase plant resistance to pathogens or improve response to infection. Micronutrient enriched seed (increased Zn and Mo for wheat and these plus Cu in rice) also helps to address soil micronutrient deficiences, which are widespread in the Indo-Gangetic plain. In year 5 we found that:

- Application of micronutrients to soil of the rice nursery was slightly more effective than use of i*n vivo* enriched micronutrient seed which, in turn, was more effective than application of micronutrients to soil in production fields of rice, and also wheat.
- The mean yield response of the highest yielding varieties and promising lines of rice to micronutrient fertilization was 26-33% on two different soil types in Bangladesh, indicating that micronutrient efficiency traits should be sought in breeding programs.
- Use of micronutrient enriched seed together with addition of B to soil was the most effective treatment in a trial with two wheat varieties on nine farms in NW Bangladesh, increasing yields up to 30 and 40% compared to control and farmer seed, respectively.

Alternative soil and cropping system management practices consistent with the principles of conservation agriculture have been investigated at various sites in Bangladesh and Nepal. These include permanent raised beds, the system of rice intensification (SRI), reduced tillage, direct seeding of rice and residue return. Except for SRI, a key soil tillage factor is the elimination of puddling of soil for rice in order to improve soil physical condition. Permanent raised beds and SRI, where rice is grown more aerobically and with wider spacing between plants than in the traditional systems, represent the most radical changes. The alternative practices mostly led to higher crop productivity and savings in inputs compared to conventional practices. Highlights were:

- Increased grain yields of monsoon season rice (1-2 t/ha), wheat and mung bean were achieved with a triple crop rotation on permanent raised beds on two soil textural types. Beds reduced water use in wheat by 40-50%, reduced seed/seedling rates, and improved fertilizer N response in rice, but led to greater weed pressure.
- No yield differences were found for rice grown on beds or by the SRI compared to conventional practice in the high yielding winter (boro) season. Yield was only slightly lower with reduced water use (60%), which has economic benefits and minimizes loading of soil with arsenic (in Bangladesh).
- Direct seeding of rice coupled with surface seeding of wheat gave the highest system grain yield under lowland (heavy) soil conditions saving time, labor and water.
- Surface seeding of rice and wheat was successful on lighter textured soil, giving a no-equipment, no-tillage option for small farmers. Yield of surface seeded wheat was increased 35-70% by using mulch to aid stand establishment, conserve water, and suppress weeds. Rice yield was increased 15 % with mulch, possibly due to reduced volatilization of ammonia from the paddy. Increased straw yields provided the straw needed for mulch.
- Surface seeding of wheat was extended to more farms in the terai of Nepal and has been adopted by more that 150 farmers on heavy textured land normally left fallow after rice.

Previous research has shown that farmer yields of rice and wheat are highly variable. In year 5 we found, through surveys carried out in the Bangladesh rice-wheat site areas, that poor application of basic agronomic management principles is a major cause of low yields. Thus, higher yields were achieved with modern varieties, better nutrient and water management practices, better timing of crop production, and greater farmer technical knowledge. Farmer seed quality and seeding rates were variable and the basic issue of getting an appropriate plant stand, or number of productive tillers/m^2, appears to be important for wheat. The only fixed biophysical relationship identified was that higher yields of rice and wheat were associated with heavier soil texture. Overall, farmers were not well equipped to take advantage of technological advances.

Opportunities for ameliorating widespread soil acidity in South Asia are expanding with recent commercial efforts to import lime from Bhutan into Bangladesh. We expect that the results from liming experiments conducted in Bangladesh over the past three years will inform future efforts to promote adoption of liming over larger areas. Highlights after three years are:

- Single applications of 1.1 and 2 t/ha of lime produced average yield benefits of 0.5 t/ha and 0.6-0.8 t/ha, respectively over four to five sequential crops of rice and wheat under the soil and climate conditions of northwestern Bangladesh. A 4 t/ha lime application did not give additional yield benefits compared to the 2 t/ha rate until the fourth crop, indicating a longer residual effect.

- Lime applications did not exacerbate micronutrient availability to crops despite local soil zinc and boron deficiency problems.

PROJECT OBJECTIVES

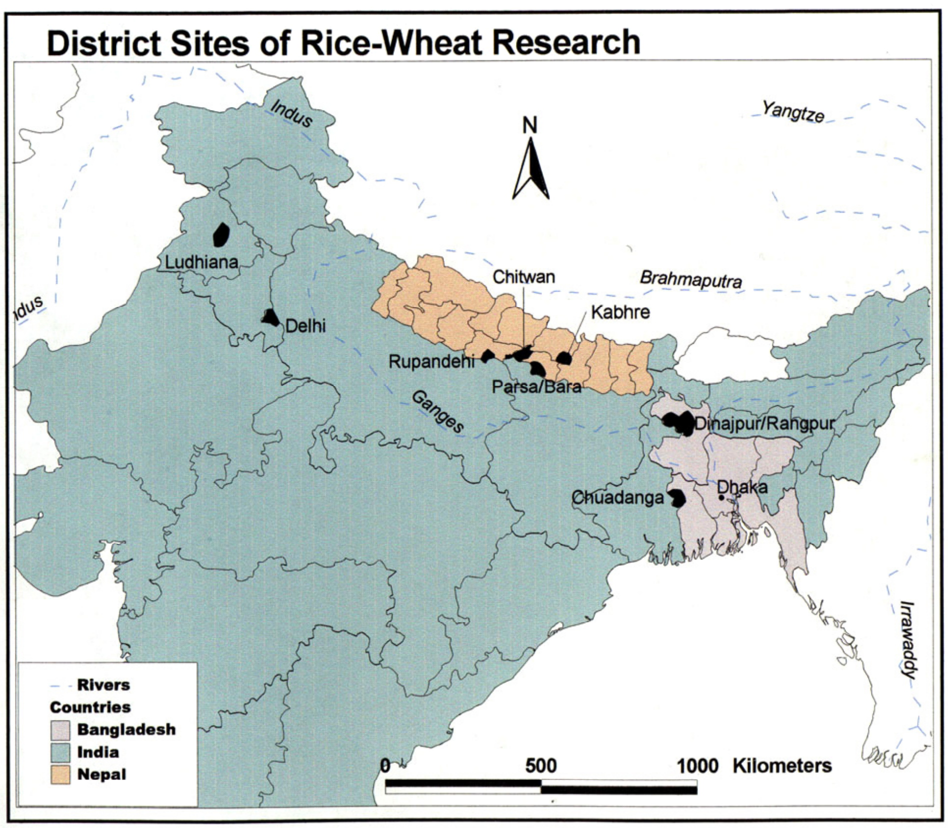
1) To identify constraints and opportunities to improve productivity in rice-wheat cropping systems of the IGP and adjacent hill regions.

2) To develop and promote adoption of improved tillage, crop establishment, and water management practices for rice-wheat systems.

3) To overcome nutrient and soil acidity constraints to crop production in soils of the Indo-Gangetic Plain.

4) To improve the agronomic and economic sustainability of rice-wheat cropping systems and the nutrition and health of farm households.

5) To use information systems and modeling as tools for improving land use and management decision making.



I. Introduction

Research carried out under the SM-CRSP program in Bangladesh and Nepal has shown that there are various soil physical, chemical and biological constraints to productivity in the rice-wheat cropping system. Physical constraints exist largely because of the puddling of soils for rice, which forms a dense tillage pan, destroys soil aggregation (and soil organic matter) and creates hard, cloddy soils for upland crops. Crop yield responses to N and P fertilization are ubiquitous and responses to K are increasing with intensive cropping. Deficiencies of the micronutrients Zn, B and Mo are fairly widespread and are not widely recognized or corrected by farmers. Micronutrient deficiencies are exacerbated by breeding programs that are releasing new varieties with greater susceptibility to deficiencies of Zn and Mo than those that they replace; a situation that highlights a disconnect between breeding programs and soil science. Farmers are generally applying less fertilizer than regional recommendations and clearly do not perceive benefits associated with using higher fertilizer inputs under their current farming practices. Lodging of crops is still a major constraint to achieving crop yield potential and this is exacerbated at increased N inputs. Farmers avoid short varieties, and are essentially accepting reduced grain yields because straw is used within the household for animal feed, building and fuel materials, or is sold in the market. Half of the soils in Bangladesh, and significant areas in Nepal, are acid yet there are no recommendations for liming, or a liming program, in either country.

Soil biological health and root health are concepts that farmers are completely unfamiliar with, yet diagnostic research that we have done using soil solarization has shown that soil biology creates important constraints for crop productivity in the region. Soil-borne pathogens and parasitic nematodes create major problems with respect to crop establishment, growth and yield. Poor root health increases susceptibility to abiotic stresses, such as drought, and reduces access to nutrients.

Given this plethora of constraints, it is very important to identify and solve the primary constraint(s) because improved management of secondary constraints will always result in sub-optimal responses if the primary constraint(s) still exists. In the five years of the project we have explored a wide variety of issues in order to identify the primary constraint(s) to productivity. We have concluded that poor root health is the major constraint to increasing crop productivity in the rice-wheat system, especially for rice. At this time we are uncertain which are the main causal organisms, but we are exploring the hypothesis that the root knot nematode *meloidogyne graminicola* is a major problem in rice. Roots of seedlings from farmer rice nurseries frequently have many galls indicating infection with this nematode, and it is clear that the root health problem with rice starts in the nursery.

The best illustration that we can give on the importance of identifying the primary constraint to crop productivity comes from a CRSP tillage experiment at Bhairahawa, Nepal. One of the factors investigated in this experiment was the impact of deep tillage prior to rice on yields of wheat following rice. A soil solarization study was superimposed on this tillage experiment. Without soil solarization, deep tillage significantly ($p < 0.05$) improved wheat yield (table 1). However, with soil solarization, yields were substantially increased in all tillage treatments and the effect of deep tillage was eliminated. The deep tillage treatment probably partially addressed the soil biological health problem by promoting deeper rooting, but was unecessary when the primary constraint was addressed.

Table 1. Effect of deep tillage and soil solarization on yields of wheat at Bhairahawa, Nepal

Tillage Treatment	**--------Yield (t/ha)--------**	
	Non-Solarized Soil	**Solarized Soil**
Conventional	3.0a[1]	5.2c
Deep tillage	4.0b	5.1c

[1]Different letters within a column or row indicate a significant difference at $p<0.05$

II. Year Five Project Activities

In the final year of the project we have concentrated on:

- Applying the knowledge we have gained of soil biological constraints to practical applications for farmers through use of healthy rice seedlings and healthy seeds.
- Determining the impact of *Meloidogyne graminicola* on crop productivity in the rice-wheat system.
- Exploring the use of permanent raised beds as a cropping systems management strategy that simultaneously addresses multiple constraints in the rice-wheat cropping system.
- Evaluation of the “system of rice intensification” (SRI) and raised beds for rice production compared to the traditional paddy system of rice production.
- Assessment of the reasons for yield variability amongst farms.
- Continuation of reduced tillage experiments that will be used for soil carbon sequestration studies in phase 2 of the CRSP.
- Continuation of lime experiments.
- Continuation/completion of graduate training programs.

III. Research Results

1. Addressing Root Health Constraints

A. Healthy Rice Seedlings

A strategy that we have developed to combat poor soil biological health is to use rice seedlings that are free from infection by pathogens and nematodes. Such "healthy seedlings" can be produced by a combination of seed treatment with the biocide vitavax-200 and solarization of soil in the rice nursery to control seed and soil borne pathogens, respectively. Rice yields are increased by up to 45% when seedlings generated in this way are transplanted into flooded soils (2001 annual report). In year 5, we extended the "healthy seedling" technology to a group of 25 farmers in NW Bangladesh. Farmers were trained how to do soil solarization then managed their own nurseries and crop, with researchers providing technical backstopping and measuring crop yield and other parameters. In this case the only treatment was solarization of nursery soil. The mean rice yield on the 25 farms was 5.2 t/ha with seedlings from solarized nurseries compared to 4.0 t/ha with seedlings from non-solarized nurseries (figure 1). In this trial, 16 of the 25 farmers were able to increase their rice yield between 30-40% just by using "healthy seedlings" (figure 1).

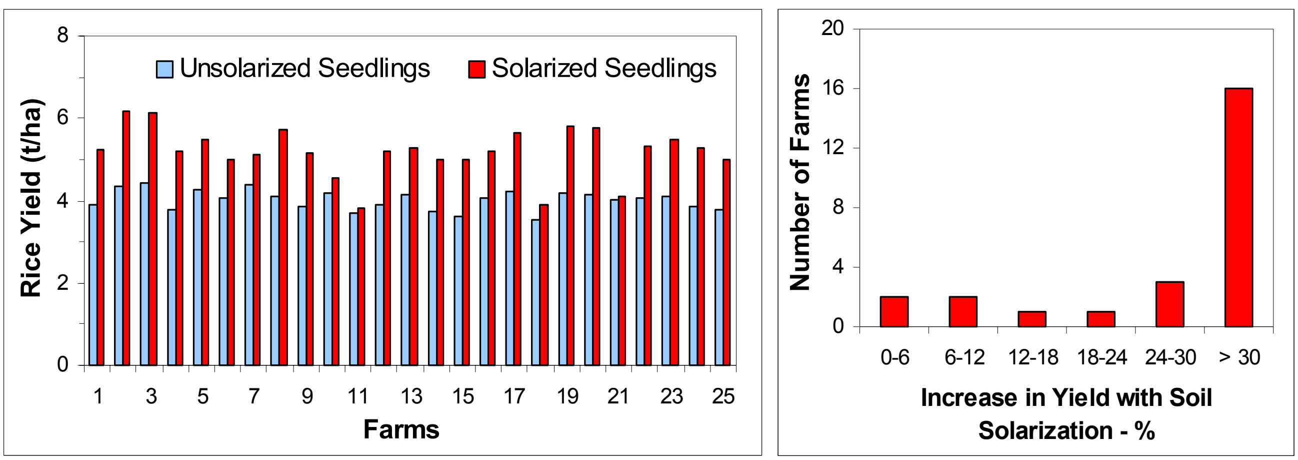


Figure 1. Effect of solarization of rice nursery soil on yields of transplanted rice on 25 farms in farmer participatory trial in Bangladesh

The effect of soil solarization on emergence and several measures of seedling health at transplanting on crop yield is readily seen in Figure 2. Emergence increased from 60 to 90%, plant height and root length were substantially increased, the number of nematode galls and fungal infection were reduced, and overall root pathology grading was much improved (scale of 0-9, where 9 is worst). Similarly, the photographs in Figure 3 show that the root system is much cleaner and root to shoot ratios are shifted in favor of shoots with soil solarization. Rice growing from healthy seedlings in farmer fields was consistently taller and greener than rice growing from normal seedlings (Fig.3 lower panel; foreground versus background).

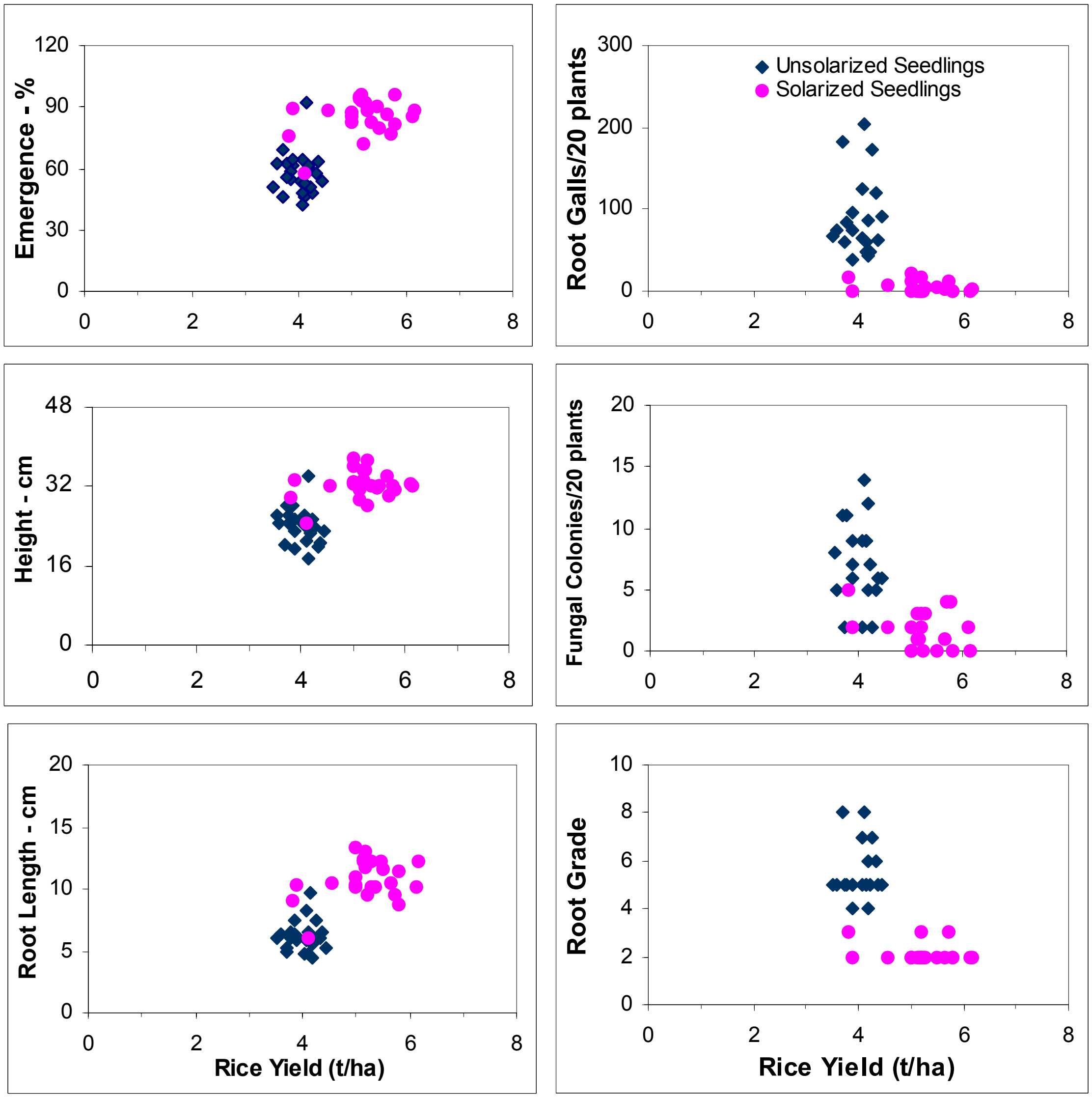


Figure 2. Effect of soil solarization on seedling emergence, growth and root health relative to crop yield on 25 farms in NW Bangladesh

We hypothesize that the healthy seedling approach is successful because pathogens and nematodes, which are aerobes, are under pressure in the flooded main field and are unable to re-infect rice plants. In contrast, pathogens and nematodes continue to negatively affect growth and reduce yields in plants that are already infected. One implication of this hypothesis is that root health would be a greater problem when rice is grown more aerobically than in the paddy, such as on raised beds or with the SRI method (see following sections).

Figure 3.
Clockwise from lower left; three examples of healthy seedlings from nurseries with solarized soil (on right) compared to seedlings from non-solarized nursery soils (on left); farmers evaluating healthy seedling nurseries (foreground) compared to normal nurseries (background and right); and rice growing in a farmer field from healthy seedlings (foreground) and normal seedlings (background

B. Micronutrient Enriched Seed

We have previously shown that use of micronutrient enriched seed can increase yields of rice and wheat on farms in Bangladesh by up to 40%. We have worked mostly with *in vivo* seed enrichment, achieved through fertilization of mother plants by either foliar or soil application of micronutrients. The impact of enriched seed on crop productivity comes from:

- increasing resistance to root diseases, and
- supplying micronutrients when these are deficient

Both seedling emergence and vigor are increased with micronutrient enriched seed; these effects are illustrated for wheat in Figure 4.

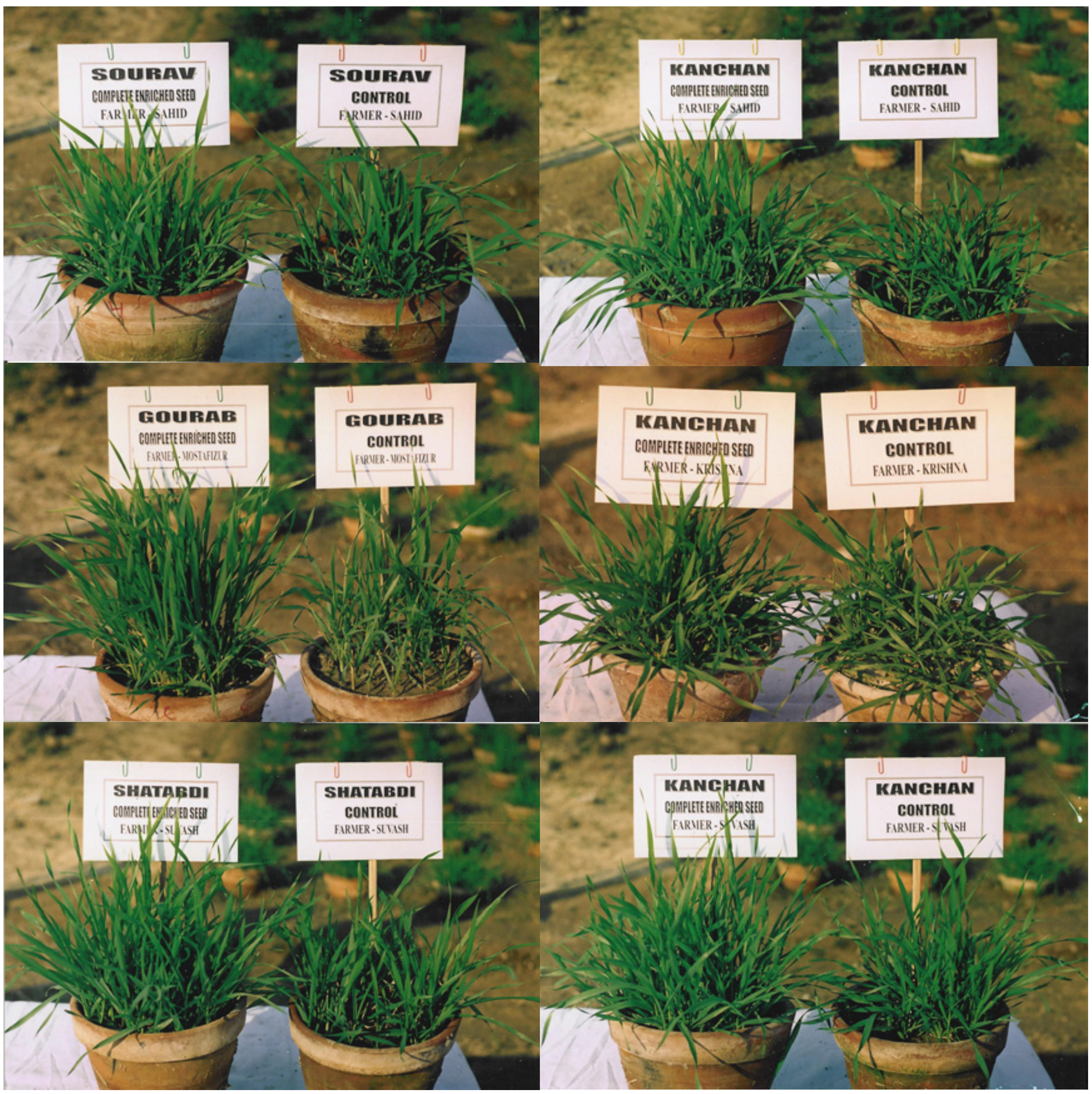


Figure 4. Effect of micronutrient enriched seed on emergence and seedling vigor for several wheat varieties growing in different farmer soils.

The concentration of Zn and Mo in grain of rice and wheat can be increased by 2-3-fold and 10-20-fold, respectively. Copper can be increased 2-3 fold in rice grain but not in wheat. Levels of Fe, Mn and B are little altered, if at all. The level of Mo in enriched seed is sufficient to meet the micronutrient need of rice and wheat, whereas the levels of Zn and Cu are not. However, plants with better root systems have increased capacity to acquire nutrients, including micronutrients, from soil.

In the 2001-02 project year we investigated:

- whether micronutrient enriched wheat seed was more effective than soil fertilization with micronutrients
- the effect of the combination of micronutrient enriched wheat seed and B addition to soil as B cannot be increased in seed, and sterility, caused by B deficiency, can be a problem
- various methods of supplying micronutrients to rice
- the response of different rice varieties and breeders lines to micronutrients

An experiment to compare micronutrient enriched seed with soil fertilization was carried out with the main wheat variety, Kanchan, and three newly released varieties (Sourav, Gourab and Shatabdi), at the Wheat Research Center, Nashipur. In all cases micronutrient enriched seed gave statistically higher yields ($p<0.05$) than control seed and addition of B to soils did not increase yields above those obtained with enriched seed (Figure 5). Yields with control seed plus micronutrient addition to soil were intermediate between the control seed alone and micronutrient enriched seed for all four varieties.

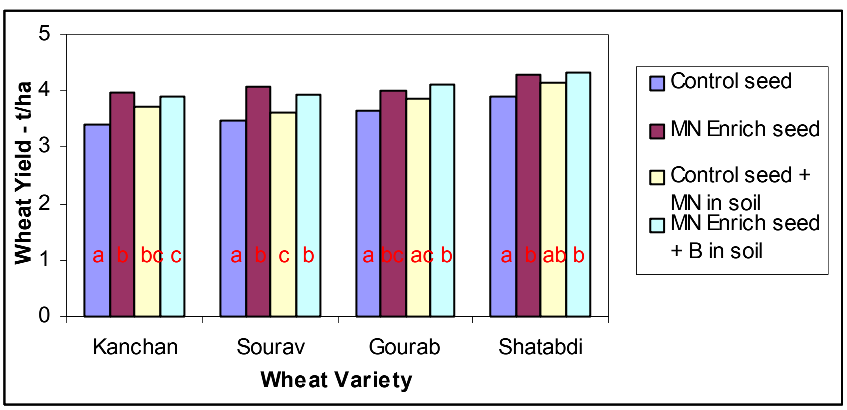


Figure 5. Wheat yields with micronutrient (MN) enriched and control seed with and without micronutrients added to soil at WRC-Nashipur, Bangladesh, 2001-02; letters indicate significant differences at $p<0.05$

Similar treatments were evaluated with Kanchan and Shatabdi varieties in replicated plot experiments on nine farmer fields in NW Bangladesh. A farmer practice treatment was included for Kanchan. Farmers in the area were not growing the newly released Shatabdi variety. Overall, micronutrient enriched seed again performed better than control seed with both varieties (Table 2.). Adding B to soil increased yields with both micronutrient enriched and control seed, indicating that B deficiency is fairly common in this part of Bangladesh.

Table 2. Effect of micronutrient (MN) seed enrichment and addition of B to soil on wheat yields in farmer fields in NW Bangladesh, 2001-02

Variety/ Treatment	Wheat Yield (t/ha)									Mean Yield t/ha	Yield Increase Over Control Seed
	1	2	3	4	5	6	7	8	9		
Kanchan											
Farmer seed/practice	3.54	3.74	3.71	1.12	2.46	1.95	1.23	2.76	3.23	2.64	**-12**
Control seed	3.81	3.66	4.29	2.11	3.48	2.03	1.19	2.71	3.76	3.00	**NA**
Control seed+B	4.40	3.95	4.12	2.61	3.42	2.72	2.54	2.36	3.89	3.34	**11**
MN enrich seed	4.01	4.17	4.95	2.93	3.45	2.70	1.93	2.75	3.68	3.40	**13**
MN enrich seed+B	4.57	4.27	5.13	3.01	3.54	2.97	2.67	2.63	3.89	3.63	**21**
Shatabdi											
Control seed	3.96	3.98	4.28	3.42	3.66	0.11	0.48	3.32	3.63	2.98	**NA**
Control seed+B	4.47	4.78	4.35	3.76	3.62	3.10	2.40	3.09	3.55	3.68	**23**
MN enrich seed	4.43	4.60	4.73	3.59	3.64	0.19	0.82	4.40	3.54	3.33	**11**
MN enrich seed+B	5.28	4.81	4.90	3.78	3.72	2.93	2.41	3.68	3.79	3.92	**31**

An experiment to evaluate different methods of supplying micronutrients to the rice variety BR 32 was carried out at WRC-Nashipur in the T. aman season of 2000. The highest yield was obtained with addition of micronutrients to the soil of the rice nursery, followed by micronutrient enriched seed and foliar application of micronutrients rice in the field (Figure 6). Fertilization of the main field soil, foliar application in the nursery and seedling soaking were less effective. Soaking seedlings longer than 2 hours reduced yields substantially (Figure 6), and it is possible that a shorter soaking time would have given higher yields.

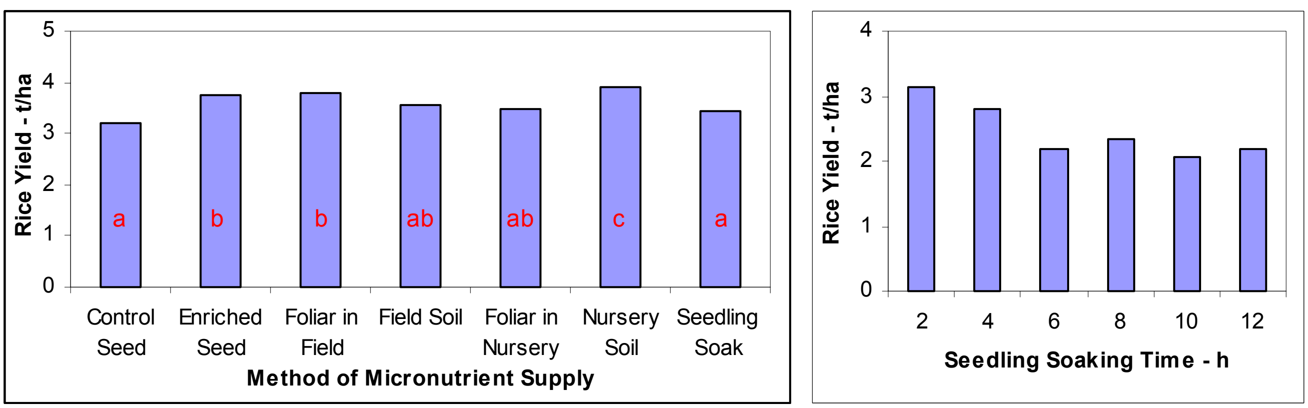


Figure 6. Effect of micronutrient supply methods on yield of BR 32 rice in the T. aman season at WRC-Nashipur, Bangladesh, 2000

Only small differences in yields between control seed, micronutrient enriched seed, and adding micronutrients to the nursery soil were found with BR 32 in replicated trials on six farms in NW Bangladesh in 2001 (Figure 7, left panel). No differences were found with BR 33 (data not shown). However, yields were low due to dry weather. The response of four different rice varieties to foliar application of micronutrients was evaluated at the WRC-Nashipur in 2000

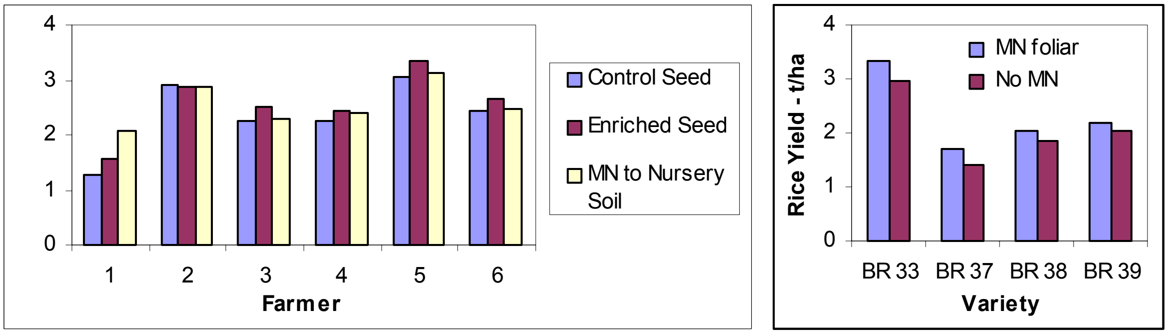


Figure 7. Effect of micronutrient supply method on yields of BR 32 on farms in NW Bangladesh in 2001 (left) and of foliar application to different rice varieties at WRC-Nashipur, 2000 (right)

(Figure 7, right panel). Yield response was significant ($p<0.05$) for BR 32 and 37, but not for BR 38 and 39.

The response of nine varieties and seventeen breeders lines to micronutrients added to soil was evaluated at WRC-Nashipur (acidic, light textured soil) and at the Chuadanga rice-wheat site (pH 8, clay loam soil) in 2001. The yield response of the highest yielding varieties/lines to micronutrients averaged 33% and 26% at Nashipur and Chuadanga, respectively (Table 3). These results indicate the importance of seeking micronutrient acquisition traits in breeding programs.

Table 3. Response of rice varieties/lines to micronutrients at WRC-Nashipur and Chuadanga, Bangladesh in 2001

Variety/Line	WRC– Nashipur Yield – t/ha		% Yield Increase with MN	Chuadanga Yield – t/ha		% Yield Increase with MN
	+ MN	-MN		+ MN	-MN	
BR 11	4.4	4.0	10	3.6	3.1	16
BR 30	3.2	2.8	14	2.6	2.1	24
Latisail				3.4	2.6	31
BR 6004-75-4-H2	3.0	2.4	25	3.6	3.0	20
BR 6415-22-3	4.0	2.2	82	3.8	3.0	27
BR 6157-38-2-4	3.0	2.2	36	3.8	3.4	12
BR 6128-24-1-3-4	3.0	2.4	25	3.6	2.4	50
BR 6420-13-1-6	3.6	2.8	29			
Mean	**3.46**	**2.69**	**33**	**3.49**	**2.80**	**26**

2. Impact of *Meloidogyne graminicola* on Rice Productivity

The possibility that the root-knot nematode *Meloidogyne graminicola*, which commonly infests the roots of seedlings in rice nurseries, is a major constraint to rice productivity is being investigated through two PhD research programs. Jon Padgham has completed a study in Bangladesh that:

- surveyed the extent of soil infestation with *M. graminicola*
- assessed the impact of *M. graminicola* on rice productivity
- investigated the survival and infectivity of *M. graminicola* in flooded and nonflooded soil
- established the host status of other crops used in the rice-wheat rotation to *M. graminicola*

Ramesh Pokharel from IAAS, Nepal is completing coursework at Cornell. His research will investigate the variability in virulence of *M. graminicola* isolates from Nepal and the susceptibility/resistance of released varieties and promising germplasm of rice and wheat.

(i) Soil infestation with *Meloidogyne graminicola*

A bioassay test was developed to assess soil infestation with *M. graminicola,* which was evaluated during the pre-monsoon period between wheat harvest and monsoon rice planting. Ten farmer fields in Natore district, NW Bangladesh were surveyed at each of two locations in 2000, and 21 fields and 7 rice nursery seedbeds were surveyed at one location in 2001. Infestation levels in 2000 ranged from low to moderate (Table 4), whereas two-thirds of the fields surveyed in 2001 had root-galling severity ratings of 4.0 to 7.0, on a scale of 1 to 9, indicating medium to high infestations of *M. graminicola*. In 2001, fields showed greater infestation levels than rice nurseries (Table 4).

Table 4. Results of soil bioassays of farmer soils for infestation with *M. graminicola*

	Root Galling Severity[1]	**Infestation level**
2000		
Location 1 (10 fields)	3.3	Low to Moderate
Location 2 (10 fields)	1.2	None to Low
2001		
Location 3 (21 fields)	4.5	Moderate to High
Rice Nurseries (7)	3.3	Low to Moderate

[1]RGS is on a scale of 1-9, where 1 is none and 9 is > 80% of root galling

(ii) Impact of *Meloidogyne graminicola* on Rice Producivity

Replicated plot experiments with and without the application of carbofuran (2 kg a.i./ha) to control *M. graminicola* were established on eight farmer fields and two fields at the BRRI, Rajshahi research station, and on associated rice nurseries. Carbofuran treatment eliminated root galling in the rice nurseries, and seedlings were taller and weighed more than those from untreated plots (Table 5). Root galling severity was low to moderate without carbofuran treatment. The number of juveniles (J2) stage *M. graminicola* isolated from untreated plots was substantially higher than from carbofuran treated plots (Table 5).

At midseason, rice plant height and number of tillers/plant were generally higher with carbofuran treatment in either the nursery or the field, with most differences being significant at $p<0.05$. Root galling was consistently lowered in carbofuran treated fields, but not where only the nursery had been treated. Galling severity was mostly in the moderate range, indicating that carbofuran treatment did not control the nematode very effectively. Most likely this was because the 2001 aman season was rather dry and rice was not flooded during the midseason, allowing

Table 5. Effect of soil treatment with carbofuran (C) on rice seedling growth and *M.graminicola*

Treatment	Shoot Height (cm)	Shoot Dry Wt. (g)	J2 Number	Root Galling Severity[1]
BRRI[2]				
+C	23.1a[4]	0.7a	0a	1.0a
- C	17.3b	0.4b	41b	2.9b
Farmers[3]				
+C	29.1a	1.2a	56a	1.0a
- C	23.5b	0.7b	279b	2.5b

[1]RGS is on a scale of 1-9, where 1 is none and 9 is > 80% of root galling; [2]Mean of 4 replications
[3]Mean of 7 replications; [4]Letters for each ±C pair indicate significant differences at p from <0.001 to <0.05

M. graminicola to re-establish in the soil and infect rice roots. Nevertheless, rice yields were increased by 0.2, 0.7, and 1.0 t/ha where carbofuran was applied to the seedbed only, to the field only, and to both the seedbed and field, respectively, compared to the nontreated control at the BRRI research station. Rice yield was increased by an average of 1.0 t/ha on five farmer sites where carbofuran was applied to both the seedbed and field compared to the control (other sites had severe rat damage). Rice yield was negatively correlated with root galling severity at mid-season. Actual relationships varied amongst sites, with yield losses in the 1-2 t/ha range as root galling severity increased from low to high for rice yields between 4 and 6.5 t/ha.

(iii) Survival and infectivity of *Meloidogyne graminicola* in flooded and nonflooded soils

A greenhouse experiment was conducted to assess the survival and infectivity of *Meloidogyne graminicola* after 0, 3, 6, 9, and 12 weeks of incubation in flooded and non-flooded soils. Infection of rice roots with *M. graminicola*, as measured by bioassay, changed little after 9 weeks incubation in flooded soil, though after 12 weeks infection decreased by 68 to 75% of the level at the beginning of the experiment. By comparison, infection of rice roots declined by over 60% after 6 weeks incubation and by 93 to nearly 100% after 12 weeks of incubation in non-flooded soil. This study demonstrates that prolonged flooding would be necessary in rice production systems in order to reduce populations of this nematode in soil, and suggests that alternating rice with a non-host upland crop would be a better control strategy.

(iv) Host Status of Selected Crops to *Meloidogyne graminicola*

Several cultivars of crops rotated with rice in Bangladesh's rice-wheat system were tested for their host status to *M. graminicola* in greenhouse trials. Rice (cv. BR11) served as a control, and was an excellent host of *M. graminicola*. All 4 cultivars of wheat and 1 cultivar of jute tested in this study were also excellent hosts. Chickpea was a good host, whereas grasspea, mungbean, and mustard were poor hosts. Sesame and one cultivar of jute tested in this study were nonhosts. The results indicate that the rotation of rice with wheat would result in a larger build-up of *M. graminicola* populations in soil compared with rotations of rice with other crops, and possibly also reducing the productivity of wheat. Opportunities exist to deliberately introduce non-host crops that are commonly grown in the rice-wheat system as an approach to control of *M. graminicola*.

3. Permanent Raised Beds for the Rice-Wheat System

The rice-wheat system has developed to optimize the soil environment for rice, at least as far as water retention is concerned, rather than for wheat. An alternative would be to optimize the soil environment for wheat and to grow rice without puddling or flooding soils. Until recently, this approach has been rejected by rice agronomists on the basis that such a system would lead to high yield penalties with rice and increased problems with weeds.

Raised beds are widely used in agriculture in developed countries and have proven to be an excellent option for wheat (Limon-Ortega et al, 2000a and b). Permanent raised beds offer opportunities to address various soil and management constraints in the rice-wheat system, with the following hypothesized outcomes:

- Increased yields of wheat, but ??? for rice.
- Rebuilding of soil aggregation over time (due to the reduced tillage practice), providing deeper rooting and better air and water relationships in the soil.
- Reduced water use, as furrow irrigation is more efficient than flood irrigation.
- Increased fertilizer N recovery for both rice and wheat, by banding of nitrogen into soil between two rows on a bed. The latter is especially important for rice where fertilizer N recovery is generally poor (20-40%) due to the difficulty of avoiding losses by denitrification and ammonia volatilization in flooded soil.
- Reduced requirements for seed and transplants.
- Reduced crop lodging and foliar disease, due to stronger plants and better air movement in the field.
- Increased weed pressure with wide spacing between rows on adjacent beds (rice and wheat) and more aerobic rice culture.

Experiments to compare crop productivity and other parameters on beds and on flat land have been established at two sites in Bangladesh (Nashipur and Rajshahi) on soils that differ in texture. The soil at Nashipur is a sandy loam and that at Rajshahi is a silty clay loam. The beds were established by hand with similar dimensions (15 cm high, 75 cm furrow to furrow) to those created by the FIRBS bed former developed at Punjab Agricultural University (see Rice-Wheat Consortium web site at http://www.rwc-prism.cgiar.org/rwc/bed_planting.asp). A triple crop rotation rice-wheat-mung bean was used. Growing short duration mung bean between wheat and rice is attractive to farmers who have irrigation, and has become feasible with newly released short duration varieties. Two rows of plants, 20 cm apart, were planted on the beds for all crops. Conventional spacings and plant densities were used on the flat. Wheat and mung bean were direct seeded and rice was transplanted with a single 10 day old seedling/hill. The experiments included three N levels (50, 100, and 150% of recommended N) and two placement methods (band and broadcast). The bed and conventional practices are shown for rice and wheat in the photographs of Figure 8.

The effect of planting on beds on crop yields across all N treatments is shown for the two sites in Figure 9. To date, yields of all three crops have been higher on the bed compared to conventional practice on the flat at both sites. Surprisingly, the largest yield increase was observed with rice, which challenges the concept that a paddy, with continuous flooding,

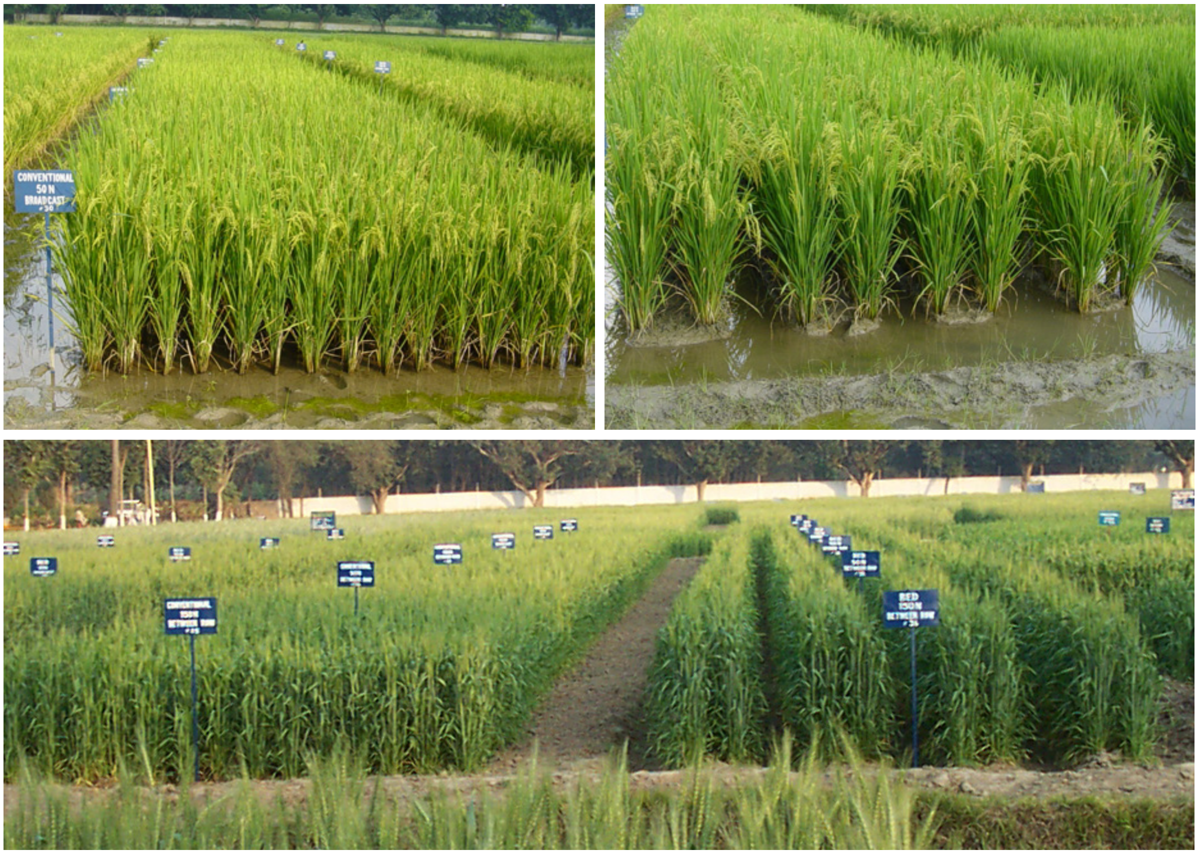


Figure 8. Plots of rice (upper) and wheat (lower) on raised beds(right) and conventional flat land (left) in the permanent bed experiment at Rajshahi, Bangladesh

throughout much of the growth period, is the optimum environment for rice. The yield increases were achieved at much lower plant populations than normal, therefore also saving seed and seedlings.

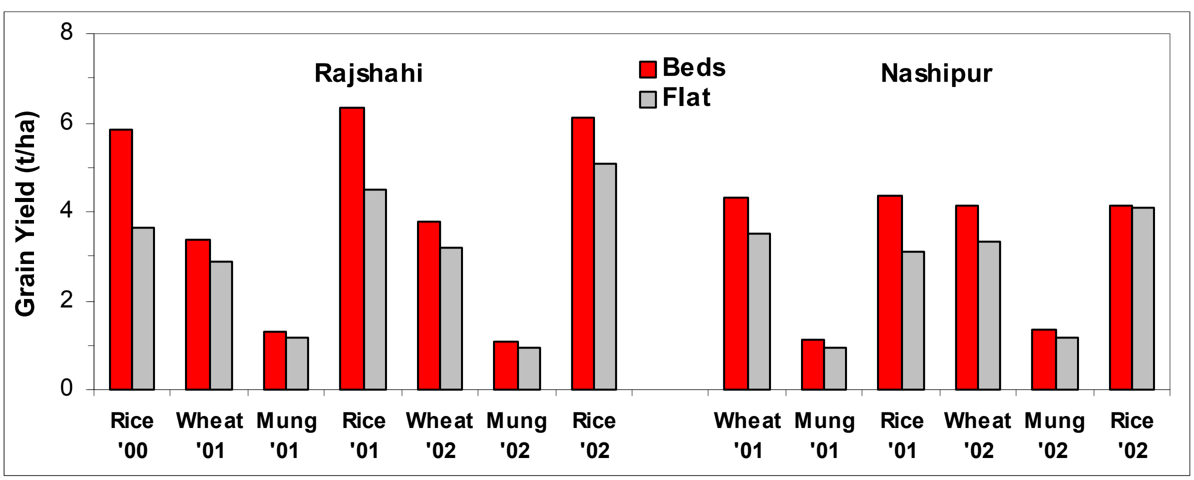


Figure 9. Yields in a rice-wheat-mung bean triple crop rotation on raised beds compared to conventional practice on flat land at Nashipur and Rajshahi, Bangladesh

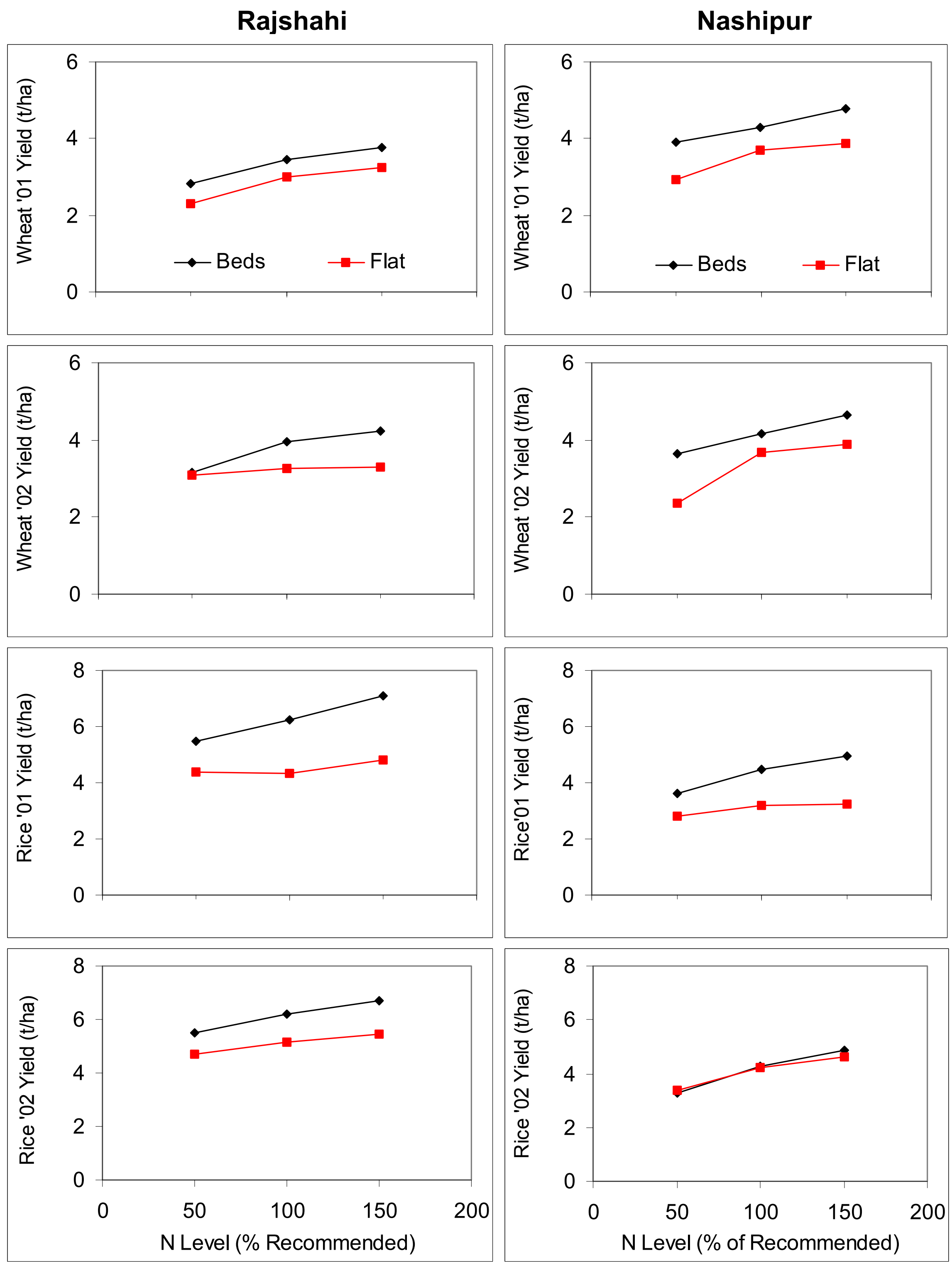


Figure 10 Wheat and rice yield responses to nitrogen fertilizer additions on raised beds versus conventional flat land at Rajshahi and Nashipur, Bangladesh, 2001 and 2002

The response of rice and wheat to nitrogen inputs is shown in Figure 10. With a few exceptions, wheat and rice yields from the flat treatments were less responsive to fertilizer N than the bed treatments at both sites. However without a zero N level control to determine soil N contributions, it is unclear whether bed planting actually improves fertilizer nitrogen recovery over conventional flat practice. Despite our hypothesis that band placement would improve N recovery over conventional broadcast fertilizer applications, few differences in crop yields due to nitrogen placement were observed at either site. Only wheat 2001 at Nashipur and rice 2001 at Rajshahi showed significant yield increases due to banding of urea fertilizer relative to broadcast placement. Crop N analysis is ongoing to further elucidate possible improvements in N recovery from the various treatments.

Despite no puddling and a lighter soil texture, 14 to 17% less supplemental irrigation was required in the beds relative to the conventional flat treatments at Nashipur in rice and 21% less irrigation in wheat. Wheat and rice cultivated on raised beds at Rajshahi needed 40% and 33% less irrigation, respectively, compared to conventional flat practice.

Unexpectedly, weed density appears to be reduced under raised bed cultivation. At Rajshahi, weed pressure was reduced in the beds compared to the conventional flat treatments in each of the three crops in the rotation (Figure 11). Similar weed observations were made at Nashipur.

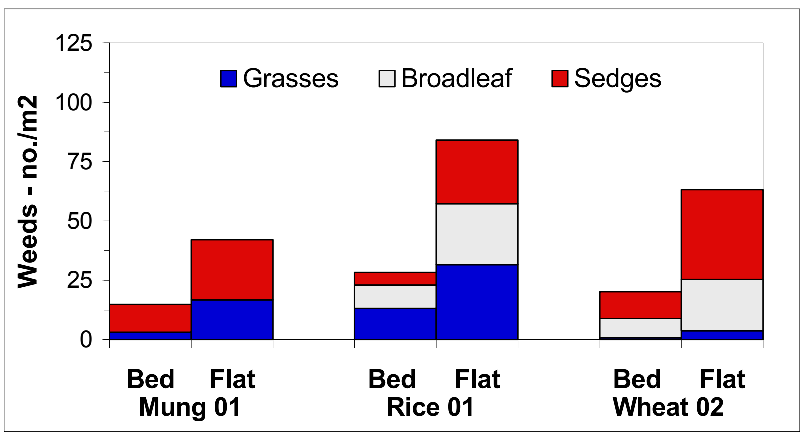


Figure 11 Weed density by type and crop on raised bed and conventional flat treatment plots at Rajshahi, Bangladesh 2001

The crop yield advantage of the raised beds will likely increase over time for wheat and mungbean as the soil physical condition improves. However, it is not clear what will happen with rice as the soils should gradually become more permeable. Perhaps, compacting the bottom of the furrows would reduce downward movement of water while maintaining lateral infiltration rates, effectively maintaining the water retention advantage of the paddy.

The bed system is most easily undertaken by farmers with tractors and large fields and is more difficult for resource poor farmers with small land holdings. It should be noted, however, that farmers do make and break raised beds by hand for wheat production on heavy soils in the Kathmandu valley in Nepal, showing that they are willing to invest labor into this practice.

4. Comparison of Conventional Rice Production with SRI and Raised Beds

The SRI method of growing rice is being evaluated by farmers and national research systems across the rice growing world. The essential elements of SRI include using a young (typically 10day old) single seedling transplant per hill that is spaced more widely than current practice (usually a 30x30 or 40x40 cm spacing between plants). The soil is not continuously flooded, although data documenting a best water management practice does not, to our knowledge, exist. Compost is the recommended source of nutrients, although the experience that CARE has had with SRI in Bangladesh is that farmers generally prefer to use fertilizer. Our previous experience with SRI is that the practice may increase rice yield in the monsoon rice season up to 20% (see annual reports for 2000 and 2001), which does not bring yields anywhere near those claimed by others (commonly above 10 and as high as 20 t/ha). A non-scientist colleague at Cornell (Norman Uphoff) is the leading disciple of SRI. We have persisted with evaluations of SRI because farmers in several countries are adopting the practice, there are numerous newspaper reports of its success, and increasing interest from researchers. Unfortunately, almost none of the data being generated meets the normal standards for scientific publication.

A possible reason for our relative lack of success with SRI is that we have always maintained flooded soil, i.e. the paddy, due to the difficulty of controlling water during the monsoon season. Consequently, we initiated an experiment in the dry winter (boro) season in Bangladesh under normal and reduced water regimes, using groundwater for irrigation. Conventional production practices were compared with SRI and the raised bed method described earlier. The raised bed can be considered a modified SRI method. The experiment was carried out at BRRI research stations at Rajshahi and Joydebpur. Rice yield potential is higher in the boro season than the monsoon (aman) seasons because of higher solar radiation.

Crop yields at Joydepur ranged from 6 to almost 8 t/ha with the highest yield for the conventional practice and the SRI with 20x20 cm plant spacing (Figure 12). Wider plant spacings in the SRI treatments gave significantly lower yields. The raised bed treatment with a single 10 day old seedling/hill (SRI Bed;) yielded slightly higher than the bed treatment with 3 to 4, 30 day old seedlings/hill (Conv Bed), with yields of both similar to the 30x30 SRI treatment. Crop yields at Rajshahi ranged from 8 to 10.4 t/ha and, except for the lower yield with the 40x40 SRI treatment were not significantly different (Figure 12). At both sites, water use was greatest where water was maintained on the flat or in the furrow (beds) throughout the season. Reduced water use in the other treatments did not significantly alter crop yields at either site. As expected, weed pressure was greater with wider spacings between hills and with reduced water inputs at Joydebpur. Weed biomass data were not available from Rajshahi, but more weeds in the bed and reduced water treatments was suggested by significantly higher weeding time as compared with the other treatments.

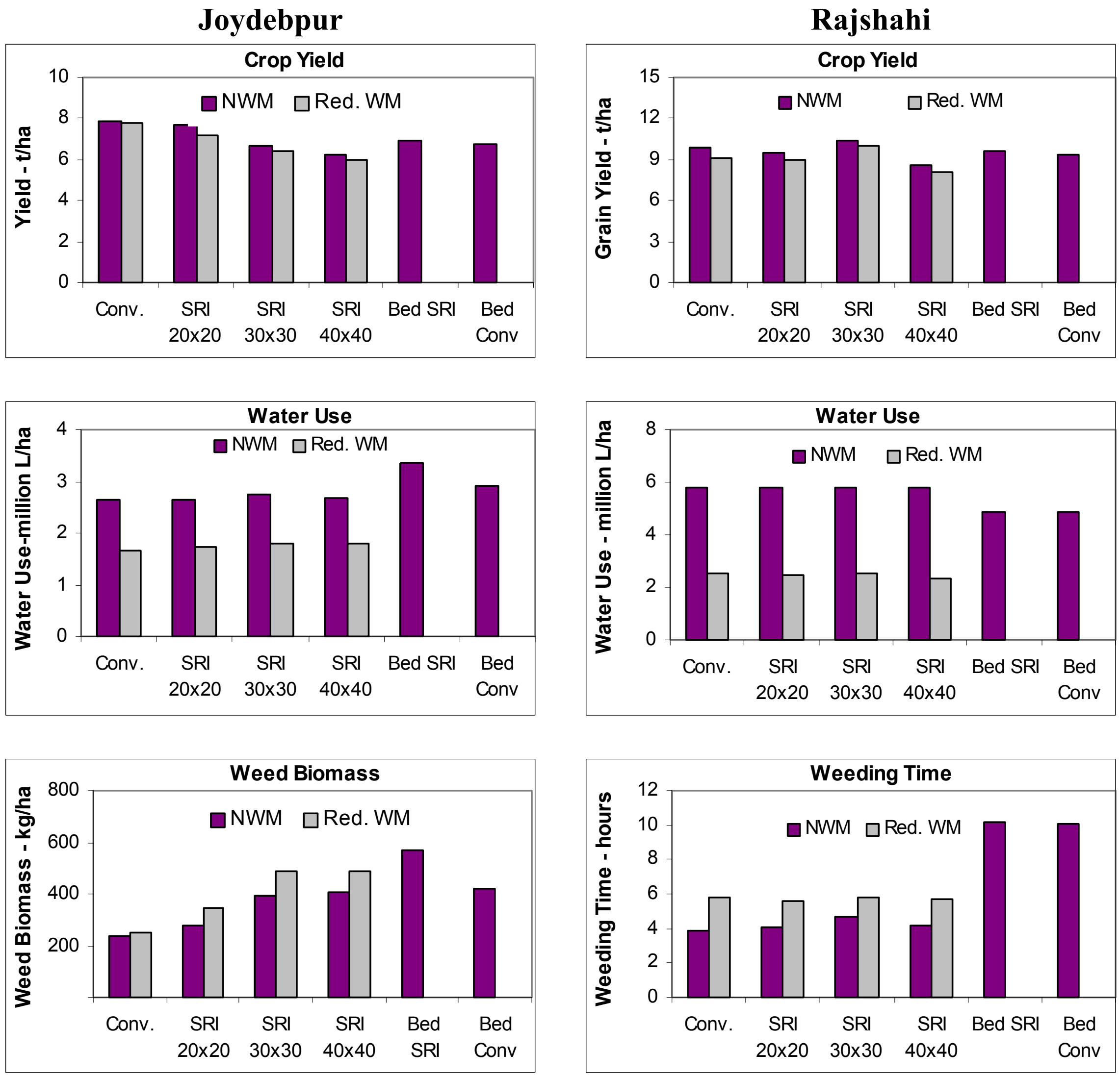


Figure 12 Rice yields, water use, weed biomass and weeding time results for SRI, bed and conventional practices at Joydebpur and Rajshahi, Bangladesh, Boro season 2002.

Wider spacing between hills led to a higher number of tillers/hill (40-50 at 40x40 cm) but fewer effective tillers/m^2 (Figure 13). Effective tillers/m^2 were lower for the bed and conventional treatments relative to the pattern for the SRI spacings at Rajshahi, but not at Joydebpur. A plot of yield versus effective tillers/m^2 (Figure 14) suggests that the highest yield with the SRI treatment at Rajshahi would have been obtained at a spacing intermediate between 20x20 and 30x30 cm or at about 390 to 400 tillers/m^2. Further, the yield potential of SRI appears to be higher than that with conventional or bed treatments. In contrast, conventional practice was as good as SRI at Joydebpur.

The boro- (winter) season results with rice on beds are surprising given that yields on beds were up to 2t/ha higher than conventional practice in the aman- (monsoon) season. Low temperature is a constraint at the beginning of the boro season. This accentuates seedling mortality, even when water levels are kept high, and may compromise the SRI method, which calls for aerobic growth of rice during its root development phase. There are likely also varietal differences in the performance of rice on beds (and SRI) and these experiments were carried out with the common varieties for each season. Reduced water use in the boro season will reduce pumping costs substantially and will also reduce soil loading with arsenic, which is a potentially devastating problem in many parts of the country.

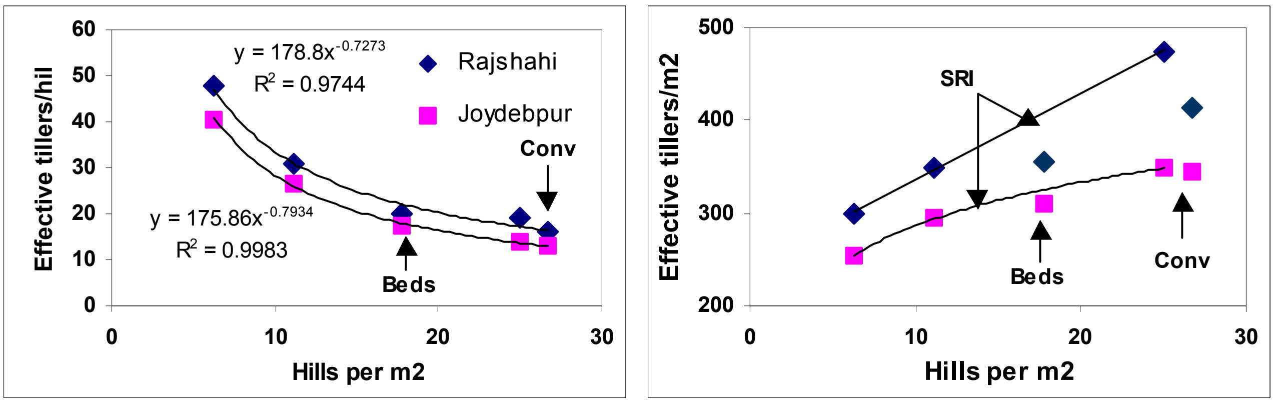


Figure 13 Effect of spacing between hills on tillers per hill and per m^2

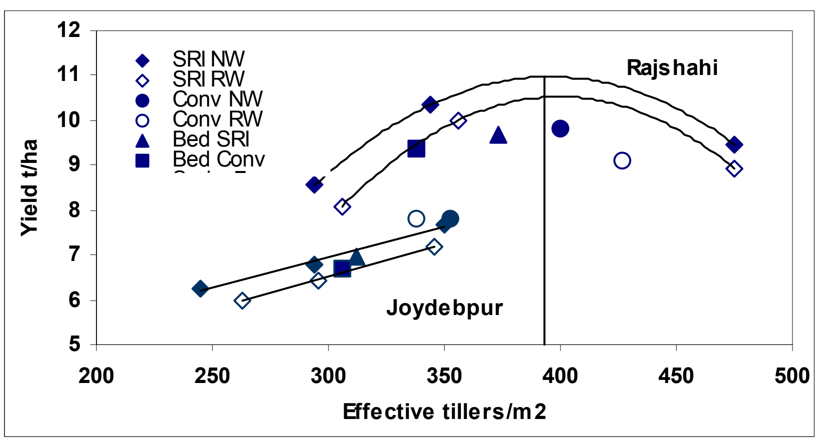


Figure 14 Relationship between rice yield and effective tillers per m^2 for SRI, bed and conventional practices. NW and RW are normal and reduced water regimes

5. Reasons for Yield Variability on Farms

A. Yield Gaps

Previous research aimed at understanding crop response to improved nutrient management showed that yield variability amongst farms remained high even when soil test based nutrient inputs were used (see 2000-01 report). It is therefore important to understand reasons for yield variability on-farms, rather than simply promoting a practice such as
a soil test based nutrient input program. We undertook a survey of 50 farms at each of the Bangladesh rice-wheat program study sites to better understand constraints to crop productivity at the farm level and the extent of yield gaps between farmers, on-farm demonstration plots and research trials. The survey did not address crop root health, which we consider to be the primary constraint to crop productivity.

Farmer yields of rice and wheat were up to 1.2 t/ha higher than the national average at both sites, but yields still increased in the sequence farmer < demonstration < research (Figure 15). Variety was a significant factor affecting yield of both rice and wheat at Dinajpur/Rangpur, with the more modern varieties (BRRI rice varieties and Kanchan wheat) giving higher yields that the older varieties (Swarna rice and Sonalika wheat).

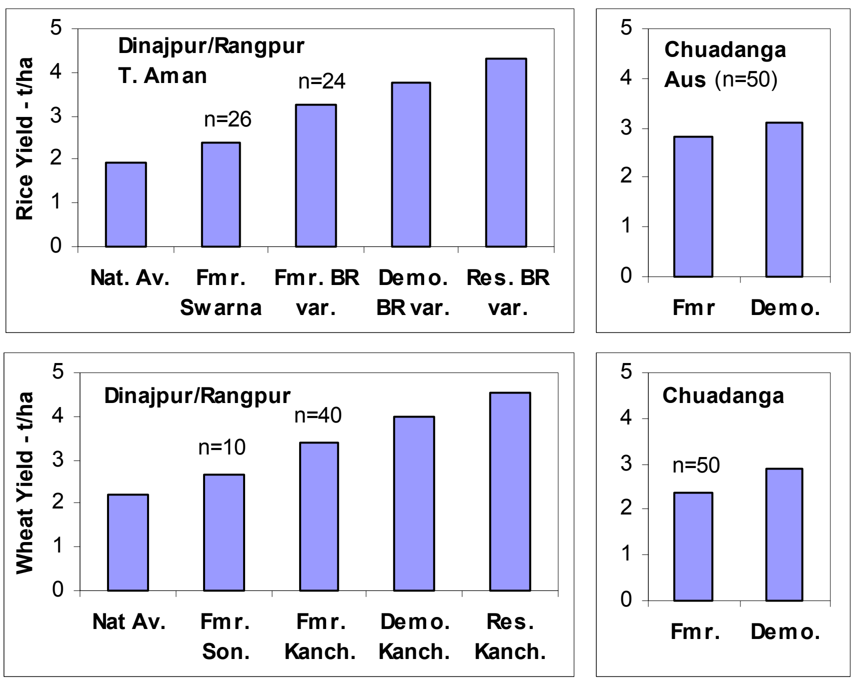


Figure 15 Rice (upper) and wheat (lower) yields achieved by farmers, on-farm demonstrations and researchers at Bangladesh rice-wheat program sites in 2001-02

B. Nutrient Inputs

Farmer average inputs of N (urea) to rice and wheat were close to or above the levels used in demonstrations and research trials at both sites, whereas their inputs of P, K, gypsum and Zn were usually less than those used in demonstrations and research trials (Figure 16). A significant relationship between N inputs and crop yield (yield = 11.8x urea input + 620; r^2 =

0.59) was only found for BRRI (BR) rice varieties at Dinajpur/Rangpur. On average, farmers at Dinajpur/Rangpur split urea input to wheat into 25% basal 50% 1st top dressing and 25% 2nd top dressing, compared to 66% basal and 33% 1st top dressing in demonstrations and research trials. The 2nd top dressing used by farmers did not increase yields.

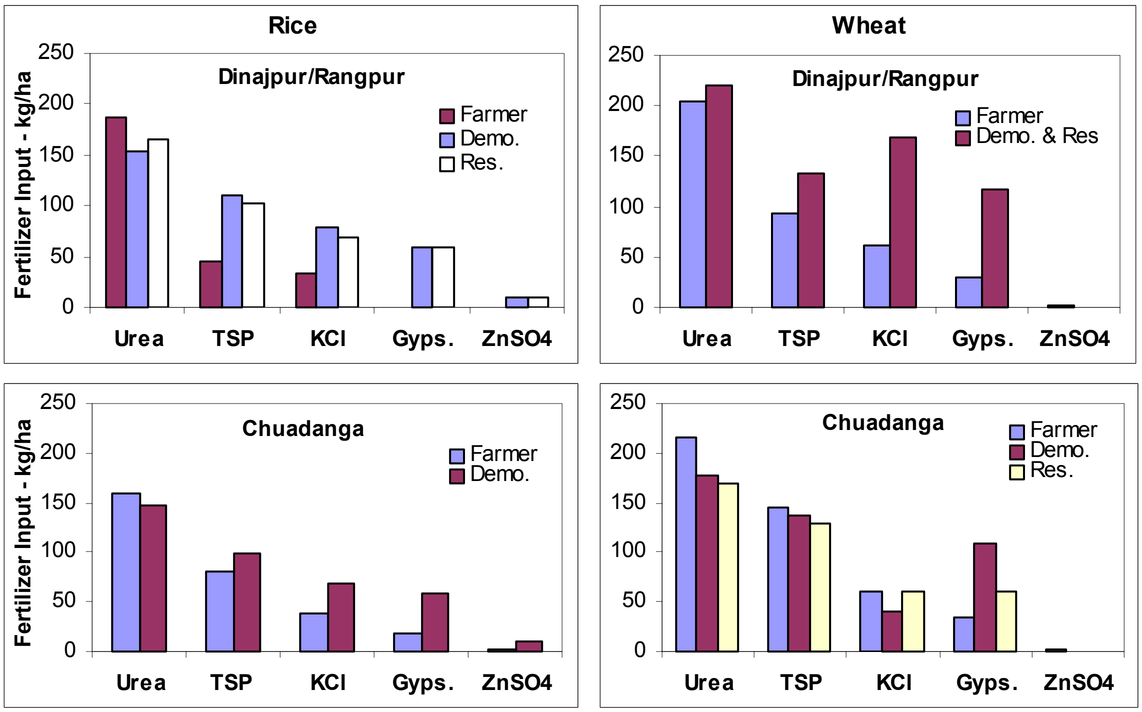


Figure 16 Fertilizer inputs to rice and wheat at Dinajpur/Rangpur

Both the BRRI (BR) rice varieties and wheat were responsive to increasing P inputs at Dinajpur/Rangpur (Figure 17). Farmer inputs of P by were higher at Chuadanga for both rice (mean of 67 kg TSP/ha) and wheat (mean of 145 kg TSP/ha) than at Dinajpur/Rangpur. Higher inputs of P are recommended for wheat because P availability increases with flooding of soils. Yield response to P was seen for both rice (BR varieties only) and wheat at Dinajpur/Rangpur (Figure 17), but not at Chuadanga, indicating that P supply was limiting farmer yields at Dinajpur/Rangpur.

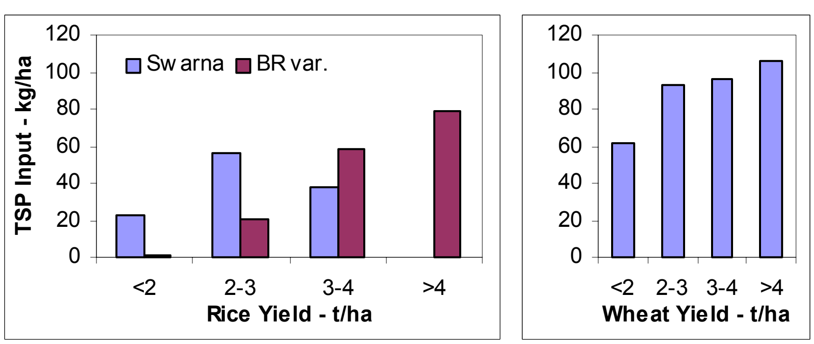


Figure 17 Crop response to P inputs on farms at Dinajpur/Rangpur

C. Irrigation Frequency, Soil Texture and Farm Size

Farmer yields of rice and wheat increased with finer soil texture at both sites (Figure 18, left panel, data shown only for Dinajpur/Rangpur). This could be related to less drought stress in the finer textured soils, but surprisingly, farmers irrigated wheat more on the finer textured soils (Figure 18, left panel). Wheat yields were strongly related to irrigation frequency, which in turn increased with farm size (Figure 18, right panel). These results suggest that irrigation frequency, and hence yield, are related to farmer economic status. However, regressions of yield by farm size were not significant for either rice or wheat.

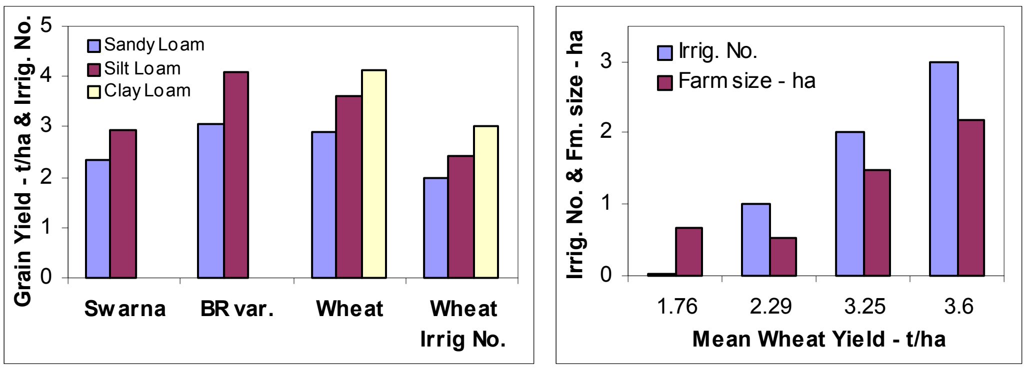


Figure 18 Relationships between soil texture, irrigation number, farm size and crop yields at Dinajpur/Rangpur 2000-01

D. Wheat Seeding Rates and Seed Quality

Wheat yields at farmer sites in Dinajpur/Rangpur were affected by both seeding time and seeding rate (Figure 19). Wheat yield was substantially reduced by seeding after December 7. Excessive heat during grain filling is common, and typically reduces yields of wheat planted after Nov. 30. Seed rates are generally high due to lack of use of drills and seeding at variable depth. Highest yields were obtained with seeding rates between 180 and 220 kg/ha and were reduced by more than half for seeding rates less than 140 kg/ha. Seeding rates above 220 kg/ha also reduced yield somewhat.

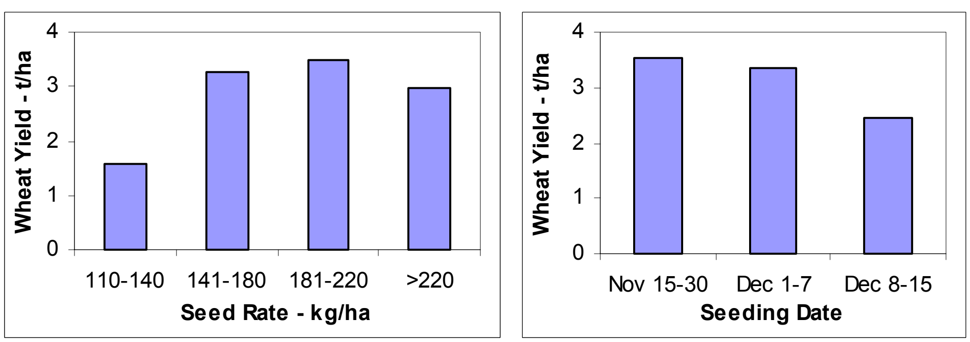


Figure 19 Effect of seeding rate and seeding date on yields of wheat at Dinajpur/Rangpur

Farmers generally used their own seed (64%) or purchased from other farmers in local markets (26%). Only 10% of the seed was purchased from the government seed supplier

(BADC). The quality of farmer wheat seed from Dinajpur/Rangpur was assessed by testing germination in petri dishes (blotter method) and by measuring seedling emergence from farmer soil (Figure 20). Germination of seed was greater than 80% in 82% of the blotter tests (Figure 21).

Figure 20 Testing seed germination/seedling emergence in petri dishes and farmer soil

Emergence of seedlings was reduced when seeds were planted in farmer soil, indicating that soil borne pathogens affect plant stand on most farms. Germination/emergence recovered when seeds were treated with the systemic fungicide vitavax (Figure 21). A simple test of seedling

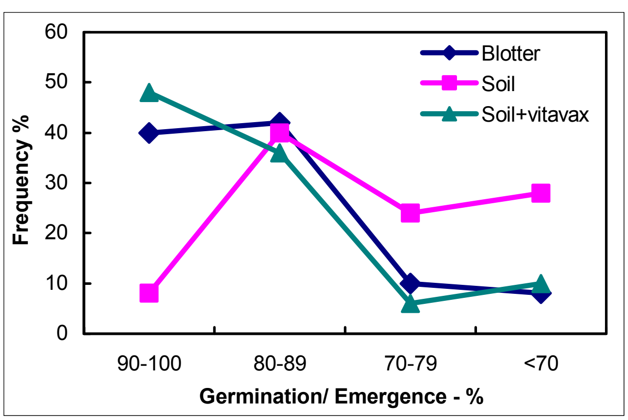


Figure 21 Germination of farmer seed by the blotter test and emergence of seedlings from farmer soil

emergence from soil could provide farmers a guide to seeding rate, indicate when seed treatment with fungicide is warranted and when a new seed source should be sought. Although wheat is an elastic crop, the basic issues of obtaining the proper plant stand and coupling this with appropriate N management to promote tillering are likely important factors constraining farmer yields of wheat.

E. Socio-Economic Factors and Multiple Regression Analysis

Farmer technical knowledge and exposure to field training through site visitations etc was positively related to crop yields. General education level, income and farm size did not have a significant effect. Multiple regression analyses using data from Dinajpur/Rangpur accounted for 70-79% of the yield variation of rice and wheat with biophysical factors being more important than socio-economic factors.

Conclusions from the survey were:

- Significant yield gaps exist between farmer yields, demonstrations on farms, and yields achieved by researchers.
- Many well established agronomic principles are not being applied well by farmers and substantial variability in crop yields occurs within apparently homogeneous areas.
- An integrated approach to crop and system management, including basic factors such as variety, timeliness of planting, seed quality and seeding rate, and nutrient, water and disease management is needed to increase yields on farms.
- Strategies are needed to improve technical knowledge of farmers.
- The survey did not address the root health constraint that we consider the primary constraint to crop productivity. However, farmers are not be well equipped to realize yield gains as ways of addressing this constraint become available, e.g. healthy seedlings of rice.

6. Reduced Tillage Rice-Wheat Systems

The common practice of puddling soils for rice production destroys soil aggregates and creates pans that can restrict root penetration. Although puddling aids water retention in the rice paddy, the poor soil structure that it creates interferes with timely establishment, crop stand and growth of wheat. Direct seeding of rice, without puddling soil, is an option being considered with increasing mechanization and projected labor shortages for transplanting. These factors led us to establish several reduced tillage experiments in Nepal that are aimed at improving the soil environment for wheat and other upland crops in the rice-wheat rotation. A tillage and crop establishment experiment on a heavy textured soil at Bhairahawa in the central terai region has:

- two tillage practices prior to rice; subsoiling (DT) and normal tillage (NT),
- two rice crop establishment techniques; puddling and transplanting (TPR), and direct seeding without puddling, using rotovator/drill attachments to a Chinese tractor (DSR), and
- two wheat establishment techniques; surface seeding without tillage (SS), and Chinese rotovator/seed drill (CSD).

The NT-TPR-CSD combination is considered conventional practice, although most farmers broadcast wheat seed and many prepare the land using a country plow. The surface seeding is a no-tillage practice and the rotovator/seed drill on the Chinese tractor does shallow tillage and seeding in one operation. The experiment has gone through five crop cycles and results for the combined five years are presented in Figure 22 Direct seeding of rice gave a significant ($p<0.05$), but small yield increase (0.2 t/ha) compared to traditional transplanting. Neither tillage nor wheat establishment treatments affected rice yields. However, all three treatment factors led to a significant difference in wheat yield. The greatest effect was observed for wheat establishment, where surface seeding increased yields by almost 1 t/ha (37%) due to more timely planting in wetter years. Sub-soiling prior to rice and direct seeding of rice increased wheat yields between 0.31-0.33 t/ha (11%) compared to their traditional counterpart practices. System productivity followed the same trends as wheat (Figure 22). The effects of individual treatment combinations on crop yield are shown in Table 6.

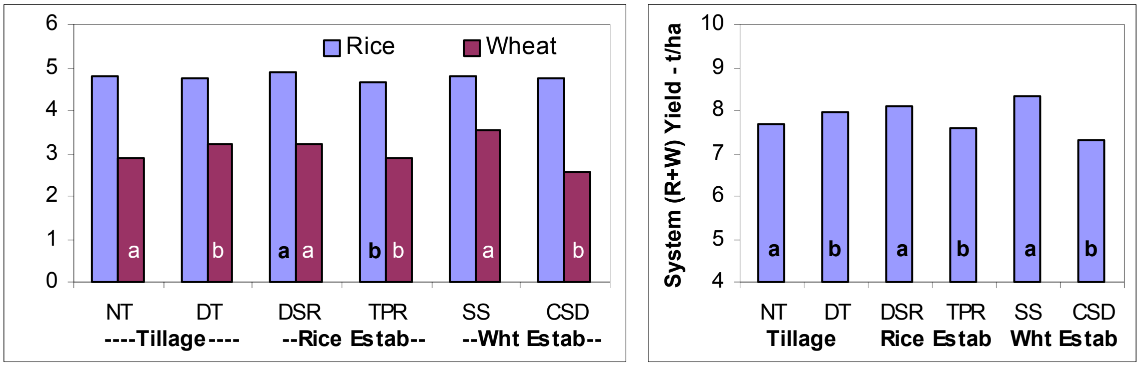


Figure 22 Effects of tillage and crop establishment treatment methods on mean yield of rice and wheat and system productivity over a 5-year period at Bhairahawa, Nepal; letters indicate significant differences between pairs within a treatment factor

Table 6 Effect of individual tillage and crop establishment treatment combinations on mean yield of rice and wheat over a 5 year period at Bhairahawa, Nepal

Treatment Till x RE x WE[1]	Rice Yield t/ha	Yield Increase %	Wheat Yield t/ha	Yield Increase %	R + W Yield t/ha	Yield Increase %
NT-DSR-SS[2]	5.00	8	3.64	69	8.64	27
NT-DSR-CSD	4.79	4	2.62	21	7.43	9
NT-TPR-SS	4.76	3	3.16	46	7.92	17
NT-TPR-CSD	4.63	NA[3]	2.16	NA	6.79	NA
DT-DSR-SS	4.88	5	3.77	75	8.65	29
DT-DSR-CSD	4.81	4	2.82	30	7.63	12
DT-TPR-SS	4.58	-1	3.55	65	8.14	20
DT-TPR-CSD	4.69	1	2.74	27	7.43	9
LSD	0.40		0.20			
CV %	6.1		9.9			

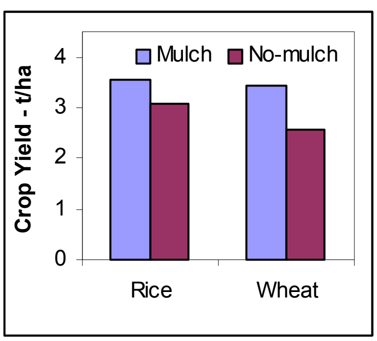
[1]Tillage x Rice Establishment x Wheat Establishment
[2]NT and DT = normal tillage and sub-soiling prior to rice; DSR and TPR = direct seeded and transplanted rice; SS and CSD = surface seeding and Chinese tractor drill for wheat
[3]NT-TPR-CSD combination is considered conventional practice

The main recommendations from the study are:

- Direct seeding of rice (DSR) can be adopted for lowland soil conditions as it produces slightly higher yields of both rice and wheat compared to transplanted rice with much less effort. It reduces the drudgery of transplanting and may save water at planting time.
- Surface seeding of wheat can be adopted on heavier soils as in produce substantially higher yield regardless of rice establishment practice. However, under dry conditions a pre-sowing irrigation will be necessary for successful crop establishment.
- If direct seeded rice cannot be adopted, sub-soiling prior to rice combined with surface seeding of wheat is an excellent alternative.

A second tillage study was carried out over a 3-year period at the Institute of Agriculture and Animal Science (IAAS), Tribuhvan University, located at Rampur in the inner terai. The purpose of this study was to determine whether a complete no-tillage rice-wheat system using surface seeding for crop establishment is feasible on a lighter textured (loam) soil. Such a system requires no equipment and would provide a no-tillage option for small, resource poor farmers. The experiment included a straw mulch treatment on all plots to help keep the soil surface moist and aid germination and seedling establishment. Mulch was removed from half of the plots after plant establishment as there are competing uses for straw, especially on small farms. Seed was primed by soaking in water prior to sowing. Different nitrogen treatments were included to confirm previous research on best N management practice for surface seeding. The experiment did not include conventional tillage treatments in the first two years but plots were split to introduce this in the third year.

Yields of rice and wheat were significantly ($p<0.05$) increased by use of mulch over the three rice-wheat crop cycles (Figure 23). Wheat yield was increased by 34% and rice yield by 15%. Mulch reduced weed competition and preserved soil moisture with wheat. The effect of mulch on rice may have been due to conservation of N through lowering of floodwater pH (see 1999 report). The physical condition of the surface of the soil was markedly better where mulch



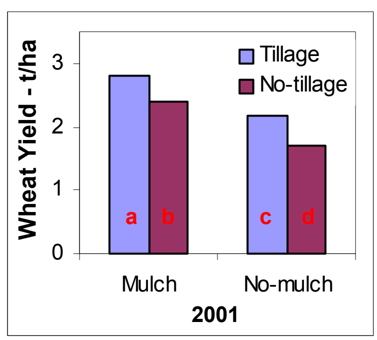


Figure 23 Effect of mulch on yields of rice and wheat over three years (left panel) and effect of introducing tillage on wheat yields in the third year (right panel) at Rampur, Nepal

was used. Consequently, plots were split in the third year and tillage prior to wheat was introduced. Tillage significantly ($p<0.05$) improved yield of wheat in both mulch and non-mulch treatments (Figure 23). However, because rice-wheat soils are so physically degraded and rebuilding of macro-aggregates is a slow process, a longer time without tillage is needed to determine whether beneficial effects persist with periodic tillage.

A second experiment to investigate the effects of rice straw mulch and N rate on surface seeded wheat yield was carried out over two years on a sandy loam soil at the WRC, Nashipur, Bangladesh (Figure 24). Straw mulch was applied at the rate of 2.5 t/ha. It was either removed at 20 days after seeding (DAS) or retained for the complete crop growth period. The mulch treatments increased yield significantly ($p<0.05$) over the no-mulch treatment at all N rates). Removing mulch at 20 DAS (M1) gave the same response as retaining mulch (M2). Most likely, the mulch aided crop establishment, which appeared to be partially overcome at high N rates that promote tillering. Both mulch treatments reduced weed biomass (experiment not weeded) at 41 DAS by 55% to 600 kg dry matter/ha. The results of this experiment reinforce the advantage of using mulch with surface seeded wheat on light textured soils.

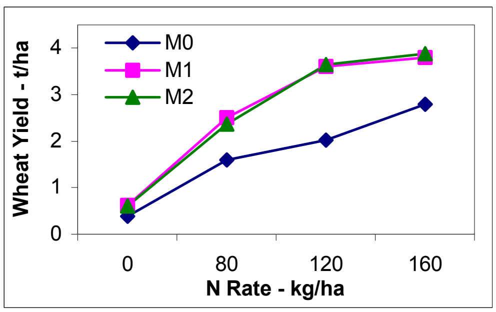


Figure 24 Effect of mulch and nitrogen additions on mean wheat yield over two years at WRC, Nashipur, Bangladesh; M0, M1 and M2 are no mulch, mulch removed after 20 days and mulch retained, respectively

Transfer of surface seeding technology was continued in Dhanusha district in the terai of Nepal. Heavy textured soils that are normally left fallow in the wheat season due to difficulty of seedbed preparation are being targeted. The program has been working in this area for two years. In 2001-02, surface seeding was tried by 40 farmers in six Village Development Committees (VDC's) in collaboration with researchers. As a result of previous efforts, 151 farmers in 11 VDC's also grew surface seeded wheat. The mean yield of SS wheat in the 40 farmer group was 2.26 t/ha. The mean grain yield of wheat sown traditionally on lighter textured soils was 2.25 t/ha, so surface seeding performed equally well.

7. Crop Residue Management with Conventional Tillage

Crop residues are not often returned to soils in Bangladesh or Nepal as they are used for fodder, fuel and thatch. Animal manure is also widely used for fuel and, although ashes are commonly mixed with composting materials and returned to soil, nitrogen is lost is this process. The amount of residue generated/ha of cropped land represents the amount of organic material that can be returned to soil to help maintain organic matter levels, improve the soil physical condition and impact diseases. Conservation agriculture principles promote return of organic materials to soil and surface residue is a key component of no-tillage agriculture (see preceding section). We initiated several experiments where residue was used in conventional tillage systems, either as mulch or incorporated into soil. The impact of the residue management treatments on soil organic matter content and on other soil properties will be evaluated in phase 2 of the CRSP program. Impacts on grain and straw yield are reported here.

An experiment at Bhairahawa, Nepal returned wheat straw to rice at the rate of 1.5 t/ha and rice straw to wheat at 3 t/ha. The lower rate of wheat straw was used because wheat straw decomposes much more slowly than rice straw and it has value for paper manufacture. Residue management treatments were mulch (RM) and incorporated (RI). Fertilizer inputs ($N:P_2O_5:K_2O$) were 100:30:30 for rice and 100:50:25 for wheat. Four cropping system cycles have been completed. Residue used as mulch or incorporated with an additional 20 kg N/ha were the best treatments, giving 7-13% higher grain yields and 0.7-1.2 t/ha/yr more straw (Figure 25). The extra straw partially offsets the return of straw to the soil. Compared to conventional NPK practice, the net input of straw in the NPK+RI+20N treatment was reduced from 3 to 2.4 and from 1.5 to 0.9 t/ha for rice and wheat straw, respectively. The straw rates used in the experiment were about 40% of the straw generated in the fertilized treatments.

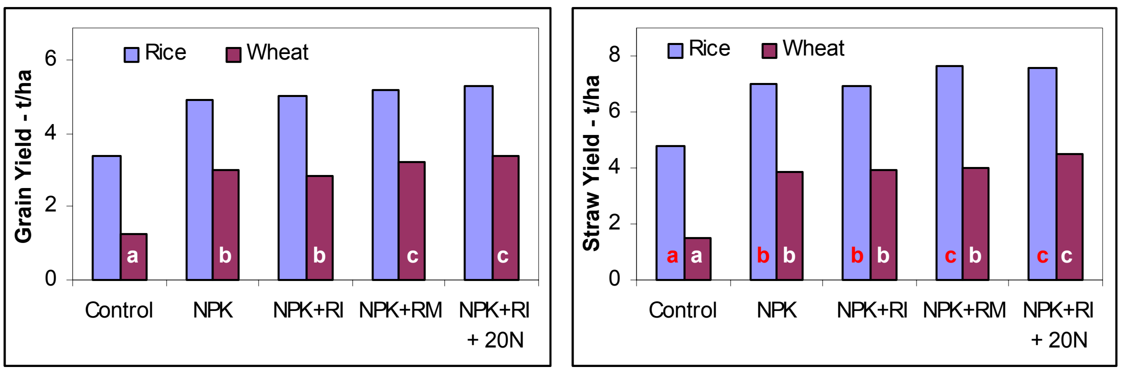


Figure 25 The effect of residue management practices on grain and straw yields over four years of a rice-wheat cropping cycle at Bhairahawa, Nepal

8. Soil Acidity and Liming

Until recently, liming has not been practiced in Bangladesh or Nepal, although soils in 15 out of the 30 agroecological zones of Bangladesh and a good fraction of Nepali soils are medium to strongly acid in reaction. Dolomitic lime imports from Bhutan are now providing Bangladeshi farmers with an accessible and affordable option to ameliorate their acid soils, which are also low in organic matter content, have poor buffering capacity and low nutrient contents.

Liming experiments were initiated in Bangladesh in 2000 to assess initial and residual effects from a single lime application and to determine whether interactions with micronutrient availability could be important given the prevalence of micronutrient deficiency problems in the region. Experiments were carried out at the Wheat Research Center (WRC) and on farm at Kaunia. Lime rates at Kaunia were 1.1 and 2.2 t/ha plus a suite of nutrient combinations; treatments at WRC included higher lime rates, 2 and 4 t/ha, as well as additional nutrient combinations.

Significant impacts of lime and nutrient additions have been reported at both sites in past annual reports (2000 and 2001). No negative impacts of lime on micronutrient availability have been observed at either site. In fact wheat sterility, caused by soil B deficiency, was reduced from 78% to 33% in 2000 at Kaunia with 2.2 t/ha lime alone.

Residual yield benefits from a single lime application are summarized in Figure 26. At Kaunia, the average yield response to 1.1 t lime over 5 crops was 0.5 t/ha, and for 2.2 t lime the average response was 0.8 t/ha. A yield benefit of 0.31 t/ha was still being seen to the 2.2 t lime rate in the fifth crop (wheat 2002), but the residual impact to 1.1 t lime was insignificant (0.17 t/ha) by that time. The average yield benefit over 4 crops at WRC was 0.6 t/ha, whether from 2 t or 4 t lime. While yield responses to 4 t lime were slightly higher than the 2 t lime rate and seemingly persisted longer, the longer term benefit may not justify the additional cost of the higher rate.

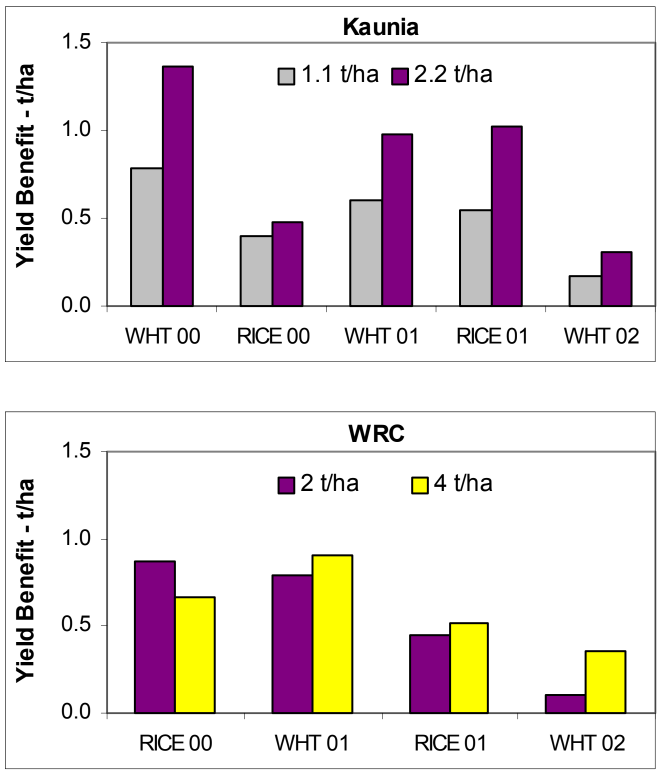


Figure 26 Yield benefit to rice and wheat over time from different lime rates (relative to unlimed control) at Kaunia and Wheat Research Center, 2000 to 2002

9. Leaf Color Chart for Improved Nitrogen Management

Leaf color, which is directly related to leaf chlorophyll content and leaf N status, is often used by farmers as a visual and subjective indicator of the crop's need for fertilizer N. The leaf color chart (LCC) is a simple and nondestructive tool, developed jointly by the International Rice Research Institute (IRRI) and the Philippine Rice Research Institute (PhilRice), to assist farmers in matching fertilizer N supply with crop needs under their existing growing conditions.

The LCC is a hardened plastic card with six green strips showing increasing greenness with increasing number. The color of the youngest fully expanded leaf from 10 randomly chosen rice plants is compared to the numbered strips. If five or more of the ten leaves have colors below a set critical value, the farmer should apply 20 kg N/ha. LCC evaluations (and indicated N applications) should be done every 7-10 days until flowering. Because LCC critical values are dependent on variety and seasonal solar radiation conditions, local calibration needs to be undertaken.

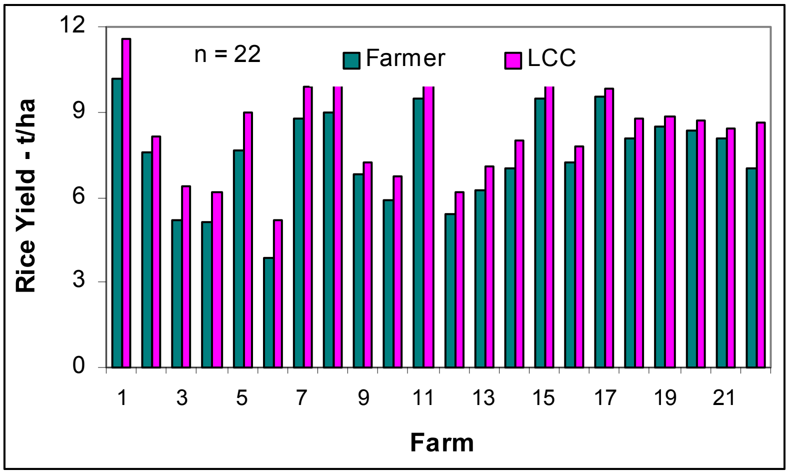


Figure 27 Response in rice yields managed with LCC tool versus farmer practice at Katunje and Bageswori villages; Nepal, 2002

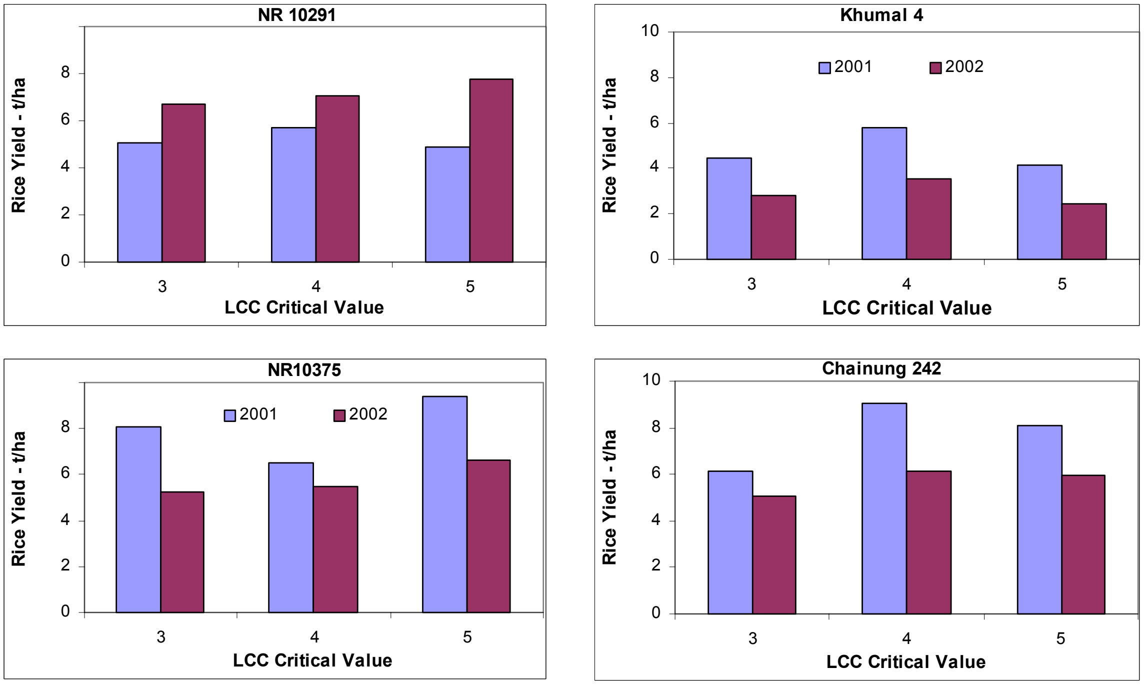


Figure 28 LCC critical value calibration study results for Kathmandu Valley rice varieties; Nepal, 2001 and 2002

Twenty two comparisons of LCC (using a critical value of 4) versus farmer practice were undertaken during the rice 2002 season in an effort to popularize and evaluate the LCC approach amongst farmers in the mid-hills of Nepal (Figure 27). Yields from the LCC plots ranged from 3-34% higher than yields with farmer practice and averaged overall 12% higher than plots following farmer practice. Farmers using 100 kg N/ha at Bageswori were able to save 20 kg N/ha with LCC management; while at Katunje, LCC saved 30-40 kg N/ha relative to the farmer practice of 150 kg N/ha.

The variability in the response to LCC relative to farmer practice on farms may have been due to incorrect critical levels for the varieties and environmental conditions of the mid-hills. Results from calibration studies conducted in 2001 and 2002 (Figure 28), indicate different LCC critical levels for rice varieties grown in the Kathmandu Valley. Despite substantial year-to-year variability, the critical levels for adding nitrogen according to LCC for Chainung 242 and Khumal 4 came out at 4, NR 10375 yielded better at a LCC value of 5 and NR 10291did best between LCC 4 and 5.

LCC is a good technique for farmers who apply ample fertilizer N to save by synchronizing application with crop demand, to minimize N losses to the environment and still increase rice yields. The question remains how effective LCC is for lower income farmers, who tend to apply fertilizer N at less than recommended rates. Often this strategy is followed because farmers do not see enough of a yield response to applied fertilizer N to warrant higher application rates. Further research is necessary to evaluate whether LCC management improves efficiency of N fertilizer at suboptimal rates, thereby increasing yields.

IV. Related Activities

A. Human Resource Development

The following training/NARS enhancement opportunities were supported by the SM-CRSP during Project Year 5:

- Dr. M.A. Saifuzzaman presented his SM-CRSP sponsored research on wheat sterility at the American Society of Agronomy meetings in Charlotte, NC, 21-25 October 2001 (see Presentations section).
- Dr. N.I. Bhuiyan, Director General of BRRI gave a departmental seminar at Cornell in November 2001 and then travelled to Washington , D.C. to present plans for the SM-CRSP phase 2 to the USAID review panel (SPARE).
- A GIS training workshop entitled "GIS Applications In Rice-Wheat System Research and Development" was held for BARI, BRRI and other Bangladeshi government agricultural agencies at BRRI-Gazipur in January 2002.
- BARI scientists, M.Bodruzzaman, S.P. Banu, A.Shaheed, M. Saifuzzaman, M.A. Rahman, A.S.M.H.M. Talukder and M. Samad, traveled to Bangkok, Thailand in August 2002 to attend the World Congress of Soil Science and to make presentations on SM-CRSP sponsored research (see Presentation section).
- Dr. (Mrs.) S. Maskey (NARC) was hosted in the Dept. of Crop and Soil Sciences as a Fulbright post-doctoral fellow, August 2002 through January 2003, where she utilized

library and analytical facilities at Cornell for her research project entitled "Enhancing farmer's livelihood through increased yield of legumes."

B. Publications

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Bhandari, D. 2001. Response of wheat genotypes to seed infection, root rot and spot blotch caused by *Bipolaris sorokiniana* and its pathogenic variability. M.Sc. Thesis. Tribhuvan Univ., IAAS, Rampur, Nepal. 96 pp.

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Poudyal, D.S. 2001. The rice root knot nematode: Its distribution and impact on rice-wheat system. . M.Sc. Thesis. Tribhuvan Univ., IAAS, Rampur, Nepal. 96 pp.

Rahman, M.A., C.A. Meisner, J.M. Duxbury, J. Lauren, and A.B.S. Hossain. 2001. Yield response and change in nutrient availability by application of lime, fertilizer and micronutrients in acidic soil within a rice-wheat cropping system. Bangladesh J. Agric. Res. 26(3): 357-365.

C. Presentations

Banu, S.P., M.A. Razzaque, J.G. Lauren, J.M. Duxbury and C.A. Meisner. 2002. Soil solarization – A cropping systems perspective research to increase productivity. World Congress of Soil Science, Bangkok, Thailand 14-21 August 2002.

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Johnson, S.E. and J.M. Duxbury. 2002. Changes in availability of Zn in several soils with redox variation resulting from flooding. American Society of Agronomy, Annual Meetings, Indianapolis, IN. 10-14 November 2002.

Johnson, S.E., J.M. Duxbury and J.G. Lauren. 2002. Effect of micronutrient nutrition on disease incidence in grain legumes. American Society of Agronomy, Annual Meetings, Indianapolis, IN. 10-14 November 2002.

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Padgham, J.L., G.S. Abawi, J.M. Duxbury and M.A. Mazid 2002. Impact of *Meloidogyne graminicola* on yield of lowland rainfed rice in Bangladesh. 4th International Conference on Nematology. Tenerife, Canary Islands. 8-13 June 2002.

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Saifuzzaman, M.A., C.A. Meisner, J.M. Duxbury and J.G. Lauren. 2001. Screening techniques for wheat sterility. . American Society of Agronomy, Annual Meetings, Charlotte, NC 21-25 October 2001.

Saifuzzaman, M.A., C.A. Meisner, M.A. Samad, J.M. Duxbury and J.G. Lauren. 2002. Management practices to help prevent sterility in wheat. World Congress of Soil Science, Bangkok, Thailand 14-21 August 2002.

Samad, M.A., C.A. Meisner, A. Rahman, M. Rahman, J.M. Duxbury and J.G. Lauren. 2002. Wheat root growth in phoshorus depleted soils. World Congress of Soil Science, Bangkok, Thailand 14-21 August 2002.

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V. Collaborators

A. Country

Country	Name	Discipline	Institution
Bangladesh	Razzaque, Dr. M.A.	Agronomy-DG	BARI
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	Hossain, M.I.	Agronomy	BARI
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	Parvin, Banu, Mrs. S.	Plant Pathology	BARI
	Paul, Dr. D.N.S.	Statistics/GIS	BRRI
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	Dahal, K.R.	Agronomy	IAAS
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	Shrestha, Dr. R.K.	Soil Science	NARC
	Shrestha, Dr.S.M.	Plant Pathology	IAAS
	Tripathi, J.	Agronomy	NARC
	Yadav, Dr. D.N.	Agronomy	IAAS

B. <u>Collaborating U.S. Institutions</u>

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Abawi, Dr.G.	Plant Pathology	Cornell Univ.
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Bergstrom, Dr.G.	Plant Pathology	Cornell Univ.
Baveye, Dr.P.	Crop & Soil Science	Cornell Univ.
Duxbury, Dr. J.	Crop & Soil Science	Cornell Univ.
DeGloria, Dr.S.	Crop & Soil Science	Cornell Univ.
Feldman, Dr.S.	Rural Sociology	Cornell Univ.
Kyle, Dr.S.	Agric. Economics	Cornell Univ.
Lauren, Dr.J.	Crop & Soil Science	Cornell Univ.
Latham, Dr.M.	Nutritional Science	Cornell Univ.
Lee, Dr. D.	Agric. Economics	Cornell Univ.
Obendorf, Dr.R.	Crop & Soil Science	Cornell Univ.
Riha, Dr. S.	Crop & Soil Science	Cornell Univ.
Uphoff, Dr. N.	CIIFAD	Cornell Univ.
Welch, Dr.R.	Plant Physiology	US Plant, Soil & Nut. Lab
Kataki, P.	Seed Physiology	Cornell-Nepal Site Coordinator
Meisner, Dr. C.	Agronomy	CIMMYT-Cornell Bangladesh Site Coordinator

C. <u>Other Collaborating Institutions</u>

Name	Discipline	Institution
Bridge, Dr. J.	Plant Pathology	CABI Bioscience, U.K.
Duveiller, Dr.E.	Plant Pathology	CIMMYT-Nepal
Hobbs, Dr.P.	Agronomy	CIMMYT-Nepal
Gaunt, Dr.J.	Soil Chemistry	Rothamsted Exp. Station, U.K.; DFID Project Director
Fuchs, Dr.G.	Physician	ICDDRB
Halderness, Dr.M.	Plant Pathology	CABI Bioscience, U.K.
Harris, Dr. D.	Plant Physiology	Univ. of Wales, Bangor, U.K.; DFID-Plant Sciences Research

Name	Discipline	Institution
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Ladha, Dr.J.K.	Soil Microbiology	IRRI
Ortiz-Ferrera, Dr.M.	Plant Breeding	CIMMYT-Nepal
White, Dr.J.	GIS/Modeling	CIMMYT-Mexico

D. <u>Graduate Students</u>

Name	Country of Residence	Discipline	Degree	Status
Cornell University				
Tarun Biswas	India	Human Nutrition	Ph.D.	Research in Bangladesh
Sanjay Gami	Nepal	Soil Science	Ph.D.	Coursework; research in Nepal
Sarah Johnson	United States	Soil Chemistry	Ph.D.	Research in Nepal
Anne Marie Mayer	England	Human Nutrition	Ph.D.	Thesis preparation; research in Bangladesh
Andy McDonald	United States	Soil Physics	Ph.D.	Thesis preparation; research in Nepal
Jon Padgham	United States	Soil Fertility/Pathology	Ph.D.	Thesis preparation; research in Bangladesh
Ramesh Pokharel	Nepal	Plant Pathology	Ph.D	Coursework; research in Nepal
IAAS, Rampur, Nepal				
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Rishi Ram Birlakoti	Nepal	Plant Pathology	M.Sc.	Research/Thesis preparation
J.J. Gaire	Nepal	Agronomy	M.Sc.	Research/Thesis preparation

VI. Acronym Definitions

BRRI	Bangladesh Rice Research Institute
BARI	Bangladesh Agricultural Research Institute
CIMMYT	International Center for Maize and Wheat
IAAS	Institute for Agriculture and Animal Science
ICAR	Indian Council of Agrictual Research
ICDDRB	Int. Center for Diarrheal Disease Research, Bangladesh
IRRI	International Rice Research Institute
NARC	Nepal Agricultural Research Council
NARS	National Agricultural Research Scientists
RWC	Rice Wheat Consortium