Nitrogen and irrigation management for direct seeded rice on light soils in a rice-wheat cropping system

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Abstract

Direct seeded rice is becoming very prominent in Southeast Asia. However, the practice is not being adapted to South Asia in the same extent. In a sandy loam soil of NW Bangladesh, four years of experiments were conducted using a two-crop system per year, as is the practice in that area. However instead of transplanting the rice, the rice was direct seeded followed by winter wheat. The trial had 3 nitrogen rates (low, recommended and high), two rice tillage practices (puddled and direct seeded) followed by wheat with the same nitrogen rates, but the tillage was conventional versus a power operated 2-wheel tractor seeder. This seeder prepares a 5-cm seedbed, sows the seed and presses the soil to the seed in one pass. Results showed that the direct seeded rice was difficult to maintain under flooded conditions. In later years, it was irrigated as truly aerobic rice. Because of the amounts of irrigation percolating through the soil, the rice yields under puddled conditions with medium nitrogen rates equaled the yields of the non-puddled rice under 150% high nitrogen rates. Weeds remained a real constraint to maintaining direct seeded rice. Next to weeds, insect infestation was greater with direct seeding-in this study mealy bugs attacked the DSR plots. Only by using herbicides and constant hand weeding were weeds able to be controlled adequately. In the last year, two rice varieties were used in sub plots and distinct differences were found in their responses to direct seeding. One of the varieties has increased nutrient uptake efficiency under anaerobic conditions, possibly phosphorus. The soils are very low in phosphorus in Bangladesh. Flooding raises the pH and reduces iron, allowing the fixed phosphorus to become available. Direct seeded rice in lighter soils of Bangladesh, where P is less available may require genotypes efficient in nutrient extraction from anaerobic conditions compared with those lines which are selected under flooded conditions. Additionally, nitrogen and irrigation must be carefully managed to ensure less nitrogen leaching losses. There were no differences in wheat yields following either direct seeded rice or puddling. Since wheat is 90% irrigated in Bangladesh (and in this experiment), wheat roots were able to grow down through the weak plow pan established by puddling.

Keywords: nitrogent, irrigation, wheat, direct, seeded, rice

Introduction

Rice, a major staple food, covers almost 80% of the total cultivated area of parts of South Asia during the monsoon rains. The second staple food is wheat and it follows rice crop in the rotation during the dry winter months. Thus the rice-wheat crop sequence has become a major cropping system in the region. To meet an increasing demand of food for the ever-increasing population of the region, the sustainability of the system productivity of these two staples has become inevitable.

The practice of puddling of rice soils is a centuries-old practice due to the weed control, improvement of water and nutrient availability, and facilitates transplanting of 3-week-old rice seedlings. Literature retains a great deal of information on the problems with a rice-wheat rotation when rice is transplanted on puddle, clayey or heavy soils followed by an aerobic crop. Oftentimes, the aerobic crop suffers due to the puddle pan formed during rice tillage that causes water not to percolate too quickly for rice but can be a root barrier for the aerobic crop thereafter (Timsina and Connor, 2001; Hobbs *et al.,* 2000; Ladha *et al.,* 2000). However, much of the rice wheat in South Asia is established on lighter soils, with the heavier soils being used for a rice-rice cropping pattern. Yet, in many areas of South Asia, wheat is mostly irrigated, making the puddle plow pan soft and thus, roots are better able to penetrate.

Direct-seeded rice (DSR) has been adapted by many growers of SE Asia due to the labor and water shortage for transplanted-flooded rice (TPR). DSR represents a way by which the rice soil is not puddle, allowing the following aerobic crop not to suffer due to poor soil qualities. Yet, DSR has not been shown effective in the lighter soils of the rice-wheat cropping system but literature does not elicit good explanations for its ineffectiveness. Thus, a 4-year experiment using rice-wheat cropping pattern was devised to try to attempt to improve the soil environment for wheat and to explore the value and effectiveness of different plant establishment techniques for both rice and wheat within the cropping system.

Materials and Methods

A sequential experiment involving rice and wheat in sequence was conducted during 1997 wet through 2001 dry seasons on a Haplaquept, non-calcareous brown flood-plain soil at the experimental farm of the Wheat Research Centre (WRC, 25048 N, 8804 E, 30 m elevation), Nashipur, Bangladesh. The soil texture was sandy loam at all depths. Growers in the area grow several varieties of rice and wheat and apply a wide range of N fertilizer rates. The optimum N rate recommended by the Bangladesh Rice Research Institute (BRRI) is 90 kg ha^{-1} for rice and by the Wheat Research Centre is 120 kg ha^{-1} for wheat. The rice-phase treatments were: one variety from 1997-1999 (BR30) and then two rice varieties thereafter (BR31 and BR32), planted under rainfed and irrigated conditions and three N regimes (0, 60, and 90 kg ha^{-1}). Rice was transplanted on 15 July with 30-d old seedlings at 0.2 by 0.15 m hill spacing and with 3-4 seedlings per hill. During the dry season, each sub-sub plot of rice was further halved to accommodate two wheat cultivation systems, power operated tiller seeder and conventional broadcast after 2 rotavator passes. The most popular variety, Kanchan, was sown at the seed rate of 120 kg ha^{-1}. The first rice crop was established in 1997 aman growing season at the Wheat Research Centre, Nashipur, Dinajpur, Bangladesh. Initially, the experiment was conducted in split plot design for rice and in split-split plot design for wheat with 4 replications.

Crop establishment and management

Rice

Prior to the rice experiment, a uniform irrigated crop of wheat was grown on the field. Wheat stubbles were cut just above the ground level immediately after harvest and removed from the field. Weeds and residues present in the field were incorporated in the field. The field was plowed, harrowed, puddled, and leveled thoroughly before transplanting. Establishment system was randomized in main plots, N regime in sub plots, and later in 2000, variety in sub-sub plots of a split-split plot design with 4 replications. Net plot size for each sub-sub plot treatment was 10.0 by 5.0 m.

The plots were irrigated every two or three days by flooding to maintain about 5 cm water above the soil surface. The rice crop was weeded three and one times for DSR and TPR, respectively. In a few years, weed biomass and dry weight was collected for assessing the weed pressure in DSR compared to TPR. Despite all the best efforts to control insect pests, some plots, especially the DSR with 0 and 60 kg N ha^{-1} were damaged by mealy bugs (*Heterococcus rehi* (Coccidae)) in some years. As a result grain yield and yield components were underestimated in those plots. One-third of the total N was applied before transplanting (TR), one-third during maximum tillering (MT), and one-third 3-5 days before panicle initiation (PI). All the plots received 80 kg P_2O_5 ha^{-1} (triple super phospate, 46% P), 80 kg K_2O ha^{-1} (KCl, 60% K), 20 kg S ha^{-1} ($CaSO_4$, 17% S), 4 kg Zn ha^{-1} ($ZnSO_4$, 36% Zn).

Wheat

The plots were rotovated and leveled thoroughly. Each sub-sub plot of the rice experiment was split into 2 halves, thus the wheat experiment was in a split-split-split plot design. For wheat, there were 2 levels of seeding method (transplanted rice, TPR and direct seeded rice, DSR as residual tillage effect) placed in the main plots, two level of tillage (conventional and minimum tillage with the power operated tiller seeder) assigned in the sub plots and three rates of nitrogen (120, 80 and 0 kg ha^{-1}) distributed in the sub-sub plots. The resulting sub-sub-sub plot was planted with 1 wheat variety with 0.2-m row spacing and with a seed rate of 120 kg ha^{-1} on 14 November. Net plot size was 5.0 m by 5.0 m. Seeds fully emerged five days after seeding. The plots were irrigated three times, once at the crown root initiation state, the next at booting stage, and the last at anthesis. Two-thirds of the total N was applied prior to seeding, while the remaining one-third was applied during PI following irrigation. The plots received 60 P_2O_5 kg ha^{-1}, 40 K_2O kg ha^{-1}, and 20 S kg ha^{-1} as supplemental fertilizers. N was applied as urea.

Yield and yield components

Grain and straw yields from both experiments were obtained from 10 m^2 harvest area per plot. Rice and wheat grain yields were adjusted to 140 and 120 g kg^{-1} moisture content, respectively. A sub-sample of plants in two 1.0 m row segments was harvested for analysis of yield components.

Results and Discussion

The grain yield of TPR was influenced significantly both by establishment methods and N rates. The number of panicles m^{-2} was less in DSR (data not shown), possibly due to insufficient uptake of nutrients from the soil because of minimum root volume and the leaching loss of nutrients that occurred. In contrast, the TPR treatment out-yielded DSR by 27-55% in Dinajpur during the first years of the experiment, less so later. Weed pressure was a factor, since good weed control was difficult to maintain during the first years of the experiment in the DSR plots. Data collected (not shown) indicates that weed biomass was more than double in DSR plots compared to the TPR plots. Due to lighter soils, water drains faster in DSR allowing weeds that are tolerant to water logging to grow rapidly. With TPR, the soil saturation is longer and weed growth is less. Drought stress and less nitrogen use efficiency may also be possibilities for the lower DSR yields. Additionally, soils in Bangladesh are much lighter in texture than those in other rice-wheat regions. Also ground water levels are deeper during the winter in parts of Bangladesh relative to other sites in the region. The interactions of tillage, seeding method and N rate on rice grain yield was insignificant.

TPR out-yielded DSR plots in every year (Table 1) due to the voluminous amounts of water that were needed, the possible leeching of N, and the lack of rice varieties that are recommended for DSR during the monsoon. During 2000 and 2001 when two rice varieties were used, BR31 out-yielded BR32 in most cases, demonstrating the need for rice varieties tested for DSR during the monsoon. Literature shows that during flooding, phosphorus that is fixed (in the case of Dinajpur, it is iron) by Fe, Al, or Ca and becomes available due to the changes of pH. Flooding causes soil pH to rise (as is the case in acid soils) or decline (as in calcareous soils) to around neutral pH of 7. Another long-term experiment in Dinajpur has shown rice yields not declining after 12 years of no phosphorus application due to flooding, while the following aerobic crop, wheat, had yield declines by half without phosphorus application (data not shown). When rice is sown directly without puddling, the crop is an aerobic crop; thus, phosphorus remains fixed. Other constraints to the DSR were more diseases and nematode attacks that are shown to be less due to puddling in the case of TPR (data not shown). There are differences in rice varietal responses to disease, nematode attack, and phosphorus deficiencies. The contrast in varietal response in this experiment indicates such variation (Table 2).

Table 1 Rice yields t ha^{-1} as affected by rice establishment methods, nitrogen rates, during 1997-1999 monsoon seasons in Dinajpur Bangladesh (TPR=transplanted/puddle rice; DSR=direct seeded/nonpuddled rice). Interaction affects were not significant; rice yields as affected by nitrogen rates or establishment methods were not significantly different.

	Nitrogen (kg ha^{-1})								
	0			60			90		
Rice Tillage/Seeding Methods	1997	1998	1999	1997	1998	1999	1997	1998	1999
	Rice Yield (t ha^{-1})								
TPR	2.92	3.17	2.75	3.63	3.75	3.38	3.33	4.17	3.75
DSR	1.25	1.88	1.21	2.28	2.92	1.75	1.54	3.25	2.38
P. level	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2 Rice yields t ha^{-1} as affected by rice establishment methods, nitrogen rates, and rice variety during 2000-2001 monsoon seasons in Dinajpur Bangladesh (TPR=transplanted/puddle rice; DSR=direct seeded/nonpuddled rice). Interaction affects were significant for rice establishment by variety; rice yields as affected by nitrogen rates or establishment methods were also significantly different.

Rice Tillage/Seeding Methods	Rice Variety	Nitrogen (kg ha^{-1}) 0		60		90	
		2000	2001	2000	2001	2000	2001
		Rice Yield t ha^{-1}					
TPR	BR-31	4.22	1.6	4.35	1.93	4.44	1.92
TPR	BR-32	4.86	1.23	4.41	1.88	4.17	2.23
DSR	BR-31	1.37	0.98	2.12	1.64	2.34	1.73
DSR	BR-32	1.22	0.42	0.82	0.71	1.15	0.96

Table 3 Wheat yields t ha^{-1} as affected by rice establishment methods, nitrogen rates, and wheat seeding/establishment methods during 1998-2001 winter dry seasons in Dinajpur Bangladesh (TPR=transplanted/puddle rice; DSR=direct seeded/nonpuddled rice). Interaction affects were not significant; wheat yields as affected by nitrogen rates were significantly different.

Tillage/Seeding Methods		Nitrogen Rates(kg ha^{-1}) 0				80				120			
		1998	1999	2000	2001	1998	1999	2000	2001	1998	1999	2000	2001
Rice Establishment/ Tillage Methods	Wheat Establishment/ Seeding Methods	Wheat Yield t ha^{-1}											
TPR	Chinese Seed Drill	1.43	1.12	1.37	1.86	2.95	2.63	3.23	3.71	3.48	3.58	3.95	4.55
TPR	Conventional	1.40	1.30	1.37	1.89	3.18	2.78	3.48	3.89	3.65	2.93	3.84	4.16
DSR	Chinese Seed Drill	1.08	0.93	1.36	1.62	3.00	2.82	3.02	3.83	3.53	3.16	3.76	4.45
DSR	Conventional	1.03	1.06	1.19	1.75	3.28	2.80	3.20	3.93	3.73	3.30	3.58	4.83
	P. Level	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

There were no interaction effects of tillage and nitrogen rates in both rice and wheat. The wheat crop was unaffected by the different tillage practices used before rice transplanting and wheat seeding for the length of the experiment, i.e. four years (Table 3). Since wheat in Bangladesh is entirely an irrigated crop, soil moisture allows the wheat roots to penetrate through the plow layer of the lighter textured soils placed by puddling during rice tillage operations. Previous experiments have shown deep tillage after and before rice had no affect on wheat yields on these light textured soils (data not shown). The soils, Haplaquepts, have no clay accumulation and as such do not have as distinct plow layer as heavier soils in other areas with a distinct 'B horizon' with clay accumulation. Predictably, grain yield of wheat was increased significantly with increasing nitrogen rate.

Conclusion

For direct seeded rice to become successful, careful selection of rice varieties that are more resistant to disease, nematodes and phosphorus deficiency is necessary. Almost all screening for rice varieties during monsoon are currently conducted under flooded conditions. Other factors including rooting development and nutrient uptake by rice roots under aerobic screening should be included. Management of DSR will require more knowledge and precision for lighter soils than with the TPR whose knowledge has been passed down for centuries. Weed control using more mechanical and chemical means will be important for the sustainability of DSR.

References

Hobbs, P.R., Y. Singh, G.S. Giri, J.G. Lauren and J.M. Duxbury. 2000. Direct seeding and reduced tillage options in the Rice-Wheat systems of the Indo-Gangetic Plains of South Asia. Presented at an IRRI Workshop Entitled "Direct Seeding in Asian Rice Systems" held in Thailand 25-28 January 2000.

Ladha, J.K., K.S. Fischer, M. Hossain, P.R. Hobbs, and B. Hardy. 2000. Improving the productivity and sustainability of rice-wheat systems of the Indo-Gangetic Plains: a synthesis of NARS-IRR partnership research. IRRI Discussion Paper Series No. 40. Makati City (Philippines): International Rice Research Institute. 31 p.

Timsina, J. and D.J Connor. 2001. Productivity and management of rice-wheat cropping systems: issues and challenges. Field Crops Research 69:93-132.