Strip planting decreases nitrogen fertilizer requirements while retention of more residue increases them in a rice-wheat-mungbean sequence on a subtropical floodplain soil

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Abstract
Conservation agriculture (CA) has not been well developed for intensively cultivated (2-3 crops yr^{-1}) rice-based cropping systems which produce large amounts of crop residues annually. Thus, we examined the effects of two crop establishment systems (minimum soil disturbance by strip planting (SP) or conventional tillage (CT)), two residue retention levels (low and high) and five N rates (60, 80, 100, 120 & 140% of the recommended N fertilizer doses (RFD) on nine consecutive crops on an Aeric Haplaquept under rice-wheat-mungbean sequence. Rice yields were comparable between the crop establishment types but system yields were significantly higher with SP in two out of three years compare to CT. Increased residue retention did not significantly influence rice yield but positively influenced system yields. No substantial differences in optimum N rate was estimated between CT and SP for 90% of maximum yield goal (MYG) for all the three years but substantially decreased in SP compared to CT in two out of three years for 95 and 99% of MYG. The N fertilizer requirement was 6-22% higher with high residue retention compared to low residue retention plots for all the three yield goal levels. High residue retention also increased soil organic carbon (SOC) at 0-6 cm depth in both tillage treatments. In conclusion, introducing CA did not alter the N fertilizer requirements of rice for 90% of MYG but reduced the requirement for 95 and 99% of MYG compared to CT. However, there was evidence that the retained crop residue immobilized N and increased the fertilizer N requirement.

Key words: Disease infestation, Nitrogen requirement, Residue retention, Rice, Soil Organic carbon

Introduction
Major progress in conservation agriculture (CA) has been made in large-scale commercial agriculture where powerful tractors are available to pull minimum tillage seeding equipment and herbicides are available and routinely used for weed control (Johansen et al, 2012). However, CA approach is not yet adopted widely in rice based cropping system particularly in South Asia (Kassam et al. 2015). This might be due to the small (<3ha) farm sizes, lack of effective weed control, and non-mechanized, intensive (2-3 crops per year) cultivation with rice-dominated crop rotations that produce large amounts of crop residues annually (12-18 ton ha^{-1}). An alternative minimum tillage method for establishing rice based on unpuddled transplanting has recently been shown to produce similar yield to puddled transplanting, but with significant cost savings and increased gross margin (Haque et al. 2016). It also decreased greenhouse gas emissions relative to conventional puddling and transplanting (Alam et al., 2016).

Puddling degrades soil structure which has an adverse effect on the growth and yield of following winter crops particularly wheat in the predominant South Asian rice-based (*Triticum aestivum L.*) cropping system (Gathala et al., 2011). Therefore, omission of puddling may reduce the cost of production of rice, create favourable soil conditions for the post-rice crop growth and yield and reduce turnaround time between crops that may increase opportunities for crop intensification and enable rice to fit in the CA system. However, minimum tillage can slow the breakdown of plant residues and reduce the release of mineralized inorganic forms of nitrogen (Hobbs et al., 2008; Kassam et al., 2009). Under minimum tillage, N mineralization rate initially tends to be lower since the soil is not as greatly disturbed and the organic residues remain on the surface (Kader et al, 2010). Hence, N in the system might be less available under minimum tillage, at least in the initial years after converting from full tillage to conservation agriculture. However, no data are available to assess the requirement for N fertilizer under the minimum tillage systems in intensive rice-based cropping systems. The present 3-year study was designed to examine the N fertilizer requirement of rice, wheat and mungbean under minimum soil disturbance and increased residue retention relative to the conventional tillage and minimal crop residue retention in subtropical rice growing climatic conditions.

Materials and Methods

The experiment was conducted on an Aeric Haplaquept in a subtropical humid climate at Bangladesh Agricultural University (BAU) farm, (24^0 43.407′ N,$90^0$26.22′ E) for three consecutive years commencing each year with the monsoon rice (T. aman) followed by wheat and mungbean. A 3-way factorial experiment comprised two crop establishment types- conventional tillage(CT) or a minimum tillage strip planting (SP), two residue retention levels- current practice with 0-20 % (low) retention and retention increased to 40-100 % (high) and five N rates (60, 80, 100, 120 & 140% of the recommended N fertilizer doses (RFD) was laid out in a split plot design with three replications (100% N rate was 75 kg Nha^{-1} for rice, 100 kg Nha^{-1} for wheat and 20 kg Nha^{-1} for mungbean). Tillage was assigned to main-plots and sub-plots represented low and high residue retention, sub-sub plots represented five N rates. The CT plots were ploughed and cross-ploughed for wheat and mungbean and puddled for rice. In case of SP, 4-6 cm wide and 5 -6 cm deep tilled zones were made (that preserved about75- 80% of untilled soil) with a row spacing of 20 cm for all the three crops. Soils were soaked overnight for softening the strip prior to transplanting rice seedlings in the strips. Nitrogen was applied in three splits for rice and wheat, but as a single basal application for mungbean. Other nutrients viz. P, K, S, Zn and B were applied at sowing. Pre emergence herbicide, Glyphosate, was used for all the three crops and an additional post emergence herbicide ‘Prepilachlor’ was used for rice in SP plots.

Results

Rice yield varied from 4.4 to 4.65 t ha^{-1} in SP and 4.39 to 4.68 t ha^{-1} in CT plots over the five N rates and two levels of residue retention for the three years (Table 1). The grain yield increased significantly by 5 % ($P<0.01$) in SP over the N rates only in the 2nd year (2013-14) out of three years. Crop residue retention over the N rates and tillage system did not affect rice yield in any of the year. The highest grain yield occurred at 100% N application or more in the first two years and at 80 % N application or more in the third year. The effect of tillage, residue and N rates on rice yield were independent.

Table 1 Effect of crop establishment, residue management, nitrogen fertilizer rate and their interactions on rice and rice equivalent yield and soil organic carbon in a rice-wheat-mungbean cropping sequence for 2012-13 to 2014–15

Treatments	**Rice yield (tha^{-1})**			**Rice equivalent yield (tha^{-1})**			**Soil organic carbon (%)**	
	2012-13	2013-14	2014-15	2012-13	2013-14	2014-15	0-5 cm	5-15 cm
Crop establishment								
Conventional	4.68	4.42b	4.39	11.1b	10.0b	9.7	1.58b	1.50
Strip	4.47	4.65a	4.44	12.3a	11.2a	10.2	1.83a	1.45
F test tillage	NS	**	NS	**	**	NS	**	NS
Residue retention								
Low	-	4.49	4.36	-	10.1b	9.6b	1.68	1.46
High	-	4.59	4.47	-	10.8a	10.3a	1.73	1.48
F test residue		NS	NS		**	**	NS	NS
N rates								
60% RFD	3.87 c	4.06 c	4.08b	8.9d	9.0d	8.3d	1.59	1.41
80% RFD	4.60 b	4.49 b	4.41a	11.3c	10.2c	9.6c	1.68	1.47
100% RFD	4.90 a	4.65 a	4.42a	12.4b	10.6b	10.1b	1.85	1.57
120% RFD	4.86 ab	4.78 a	4.58a	13.3a	11.3a	10.8a	1.73	1.45
140% RFD	4.64 ab	4.72 a	4.56a	12.5b	11.3a	11.0a	1.68	1.46
F test N rate	**	**	**	**	**	**	NS	NS
Tillage x Residue	-	NS	NS	-	NS	*	NS	NS
Tillage x N rates	NS	NS	NS	**	NS	NS	NS	NS
Residue x N rates	-	NS	NS	-	NS	NS	NS	NS
Tillage x Residue x N rates	-	NS	NS	-	NS	NS	NS	NS

Values in a column followed by the same lowercase letters do not differ significantly at $P < 0.05$ by Duncan’s multiple range test.

The rice equivalent yield (REY) ranged from 8.7 to 13.3 tha^{-1} across various treatments and years (Table 1). The REY of SP was 11-12% higher (P<0.01) than CT in the first two years but not in 2014-15. Higher residue retention had also significantly (P<0.01) increased the REY by 6-7 % for years two and three. The highest REY was obtained at 120% N rate or higher for all years. By contrast at 100 % N rate REY declined by 0.6-0.9 t ha^{-1}. At 80% and 60% N rates REY declined further in all the three years.

A significant (P<0.01) difference in soil organic carbon content (SOC) was observed in surface soil layer (0-5cm) between CT (1.58%) and SP (1.83%) when SOC was averaged over the residue management and N fertilizer treatments (Table 1). Sub-surface SOC was not significantly influenced by any of the treatments (tillage, residue management and N fertilizer) and their interactions. Indeed SOC was redistributed between the soil layers as influenced by tillage treatments with a buildup in the surface layer of SP soil while it was declined at the sub-surface layer compared to the CT soil. The buildup of SOC due to higher residue retention was also found pronounced at the surface layer compared to the sub-surface layer.

The REY of different N treatments under CT and SP averaged over residue retention fitted well against N rate with a quadratic equation ($y = a + bx + cx^2$) (Fig 1A).This crop response curve shows that rice yield was depressed at greater than100% N rate in SP during the initial year of the experiment while it responded positively gradually at higher N rate in the succeeding two years. However, if the rice yield data of different N treatments under low and high residue management were averaged over tillage management and plotted against N rates, then the crop response curve shows that the rice yield increased with the increase of N application under higher residue retention. However, it declined with the highest N rate (140%N) in both the years under lower residue retention. The yield gap between residue treatments became closer over time.

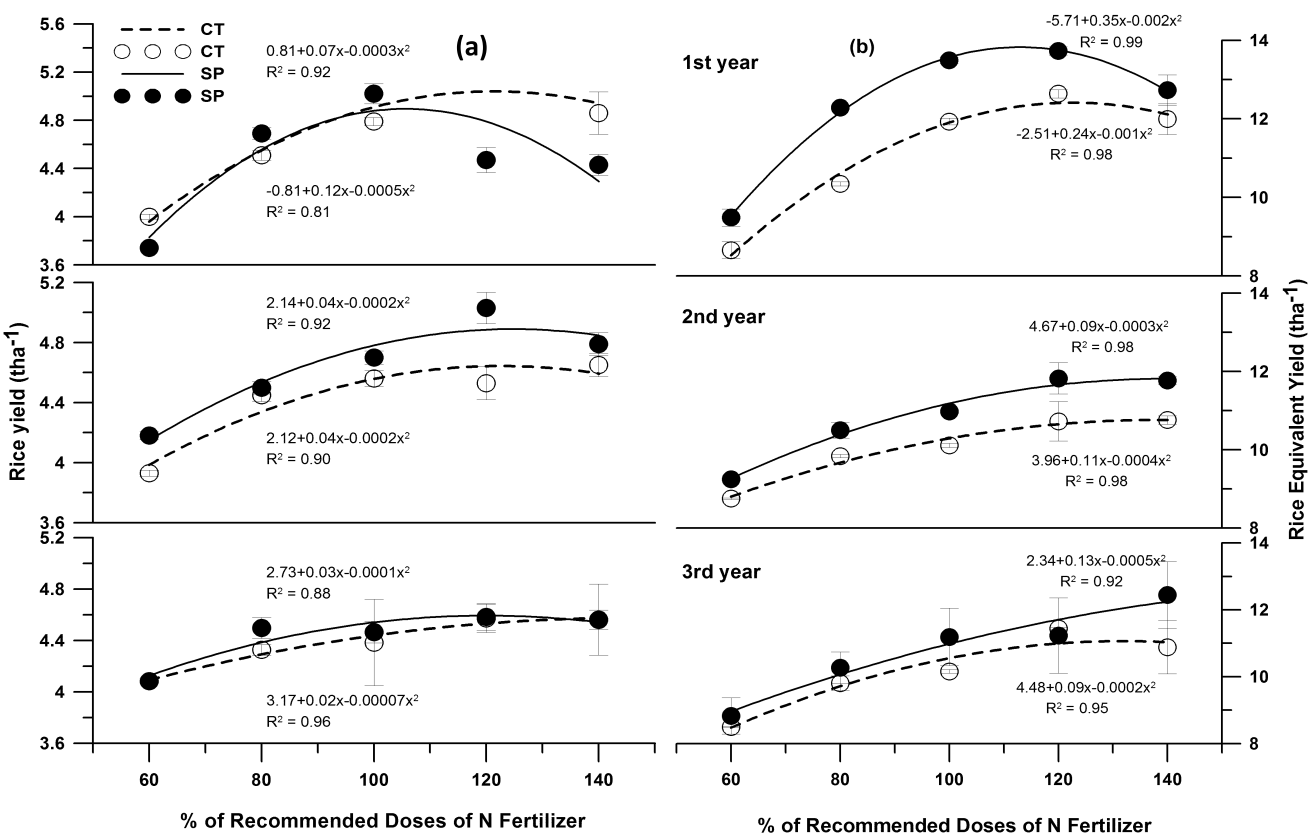

Figure 1 Crop response curve for nitrogen against rice yield (a) and rice equivalent yield (b) under conventional and strip planting systems for crop year 2012–13 to 2014–15

When the REY under CT and SP was averaged over residue retention and fitted against N rate values peaked at 120 % RFD for both the tillage system in the initial year of experimentation when rice did not receive any crop residues from the previous crop (Fig 1B). However, the crop response curve in the succeeding years showed responses to higher N rates, particularly under SP. This crop response curve clearly shows that the REY of the SP was always higher than the CT.

Conclusions

This study demonstrates that strip planting of rice was feasible in silty floodplain soil of Bangladesh without any yield penalty. Moreover, the other two crops in the rice-wheat-mungbean cropping sequence were much benefitted from the adoption of SP and increased residue retention resulting a significant increase in system productivity. This might be due to conservation of soil water as these two crops were cultivated during the dryer part of the year. The N requirement of SP was comparable with CT for 90% of maximum yield goal, however, N requirement were decreased in SP as compared with CT for further higher yield goals (95 & 99%). Higher N requirement was calculated for high residue retention treatment compared to low residue retention treatment indicating increased need for N fertilizer to minimize the immobilization of N under high residue retention by C-rich rice and wheat residues.

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