Nitrogen cycling enhanced by conservation agriculture in a rice-based cropping system of the Eastern Indo-Gangetic Plain

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Abstract
Changes in soil tillage and residue retention after introducing conservation agriculture practices in intensive rice-based cropping systems in Bangladesh may alter nitrogen (N) cycling and N fertilizer requirements. An experiment was established on a farmer's field, with a legume dominated-rotation (lentil-mungbean-monsoon rice), two types of tillage - strip planting (SP) and conventional tillage (CT); and two levels of residue retention - high residue (HR) and low residue (LR). A total seven crops were studied in the 2.5 year periods (2010-13). Soil total N concentration (TN), soil N-stocks after Crop 7 and the annual N accumulation rates at 0-15 cm soil depth for 2010-13 are presented. At the end of Crop 7 (after 2.5 years), SP treatment increased the TN concentrations and N-stocks by 11 % compared to CT at 0-15 cm soil depth. The annual soil N accumulation rates were 66 kg/ha with SP while N losses were 20 kg/ha under CT during 2010-13. The N accumulation rate was 3.3 times higher with HR than LR. From 2010 to 2013, the N balance calculation indicated an estimated N gain of 51 kg/ha in SPHR but a loss in CT which ranged from 9 kg/ha in CTHR to 319 kg/ha in CTLR at 0-15 cm soil depth. The N uptake was also 14 % higher from grain and straw under SP than CT. Both SP and HR increased TN, N-stocks and N accumulation by contrast with N loss under CT. However, the turnover of TN in SPHR needs longer investigation because of likely effects on N fertiliser requirements.

Key Words
Bangladesh, denitrification, immobilization, legume-dominated rotation, minimum tillage, N input

Introduction
Conservation agriculture (CA) based on minimum soil disturbance, residue retention and diverse crop rotations has potential to sustain crop production and farm profit, mitigate soil degradation and adverse climatic impacts, while reducing water, energy and labour use in intensive rice-based cropping systems (three crops in a year) in eastern Indo-Gangetic Plain (IGP) (Johansen et al., 2012). Transitioning cultivation techniques to CA from that of conventional practice (intensive tillage and low residue retention) may alter the N cycling in crops and soil as a result of changes in soil disturbance and carbon inputs. Because limited research has been done on the effect of minimum tillage and crop residue retention on the dynamics of soil N in intensive rice-based systems in Bangladesh, this study was conducted to explore the short to medium term (2.5 years) effects of tillage and residue management on N cycling in a legume-dominated rice-based rotation in Bangladesh.

Methods
A field experiment was conducted in a farmer's field of Alipur village, Rajshahi district, Bangladesh (24°28 N, 88°46 E, elevation 20 m) starting with lentil in the cool dry season (October-March) in 2010-11, followed by mungbean in the pre-monsoon season (March-June) in 2011then rice in the monsoon season (July-October) in 2011. The same rotation continued for seven consecutive cropping seasons up to a third crop of lentil. The experiment included four replicates of each treatment in a split-plot design. The main plot consisted of three types of tillage, two minimum tillage systems:1) strip planting (SP) – in a tilled seeding zone of about 4-5 cm width and 5-7 cm deep; and untilled inter-row occupied by residue and 2) bed planting (BP) – consists of 55 cm raised bed, formed for crop land reshaped only for subsequent non-rice crops. The ST and BP were used for cultivation of non-rice crops and unpuddled rice cultivation for following rice crops; conventional tillage (CT) used for non-rice crops and puddled (wet tillage) cultivation for following

rice crops. However, only the results of SP and CT are reported here. Two levels of crop residue, high (HR) – 50 % rice and 100 % legume residue and low residue (LR) – 20 % rice and 0 % legume residue, were assigned to the sub-plots. These treatments were repeated in the same plots for each of seven crops over 2.5 years. Total N of plant and soil samples was determined using a Kjeldahl method. The soil N-stocks (kg N/ha) were calculated for 0-15 cm soil depth by multiplying N concentration by the soil bulk density at 0-15 cm soil depth. The TN concentrations and N-stocks presented were at the end of Crop 7. The annual accumulation of N rate was calculated by dividing the differences of N-stocks between the start of the experiment (2010) and the end of Crop 7 (2013) by the experimental period (2.5 years). The N balance was calculated by accounting for changes in TN between 2010 and 2013 due to the N inputs from residue, fertilizer, irrigation and rainfall, and net N removal by grain and straw. The GenStat 15th Edition software package was used for all statistical analyses. The mean differences between treatments were separated by the least significant difference (LSD) at $P \leq 0.05$ for the measured variables.

Results and discussion

Total soil N concentrations, N-stocks and N accumulation

In 2012-13, after Crop 7 (2.5 years) at 0-15 cm soil depth, the TN concentrations under SP were 11 % greater than CT and 14 % greater than the initial value across all residue treatments (Figure 1a). The N-stocks under SP were 11 % higher than CT but 8 % greater than initial N-stocks (Figure 1b). The annual N accumulation rates at 0-15 cm soil depth during 2010-13 were 66 kg/ha with SP and -20 kg/ha with CT (Figure 1c). In SP treatments, the surface placed and anchored inter-row residues between the tilled strips (which covered about 20-25 % of the surface area leaving 75-80 % undisturbed) slows decomposition and enhances TN accumulation in surface soil (Dolan et al., 2006, Dikgwatlhe et al., 2014). Conversely, intensive tillage in CT stimulated rapid decomposition of organic residue through mechanical mixing, dilution and incorporation of residue and accelerated mineralization that in turn prevented TN accumulation (Xue et al., 2015, Al-Kaisi et al., 2005).

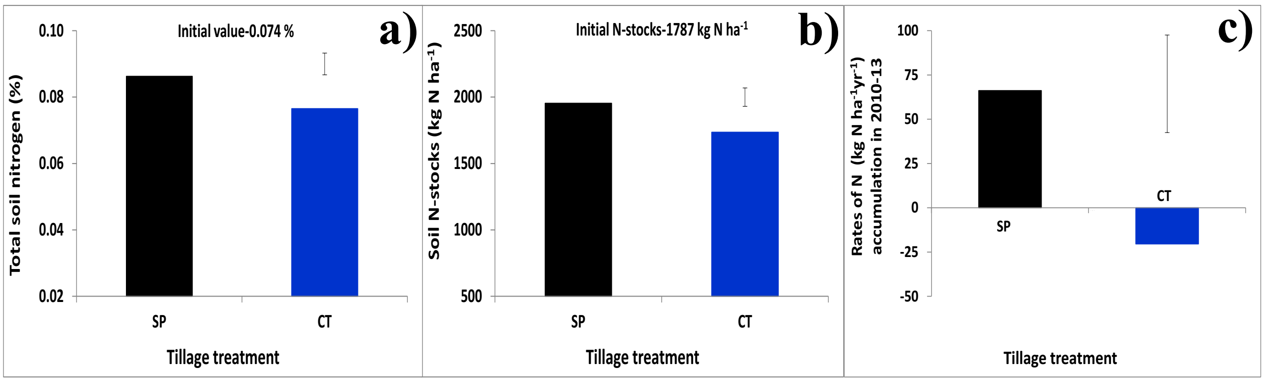

Figure 1. Main effects of tillage treatment on total soil N concentrations (a), soil N-stocks (b) in 2012-13 (after Crop 7) and accumulation rate of N rates from 2010-13 (c) at 0-15 cm soil depth. SP=strip planting; CT=conventional tillage. The floating error bar indicates the average least significant difference (LSD) at P≤0.05 for the tillage treatments. Values are means across residue levels.

The TN concentrations under HR were 4 % greater than LR after Crop 7 across tillage treatments while 11 % greater than the initial value (Figure 2a). Similarly, the N-stocks at 0-15 cm soil depth under HR were higher by 4 % and 7 % than LR and the initial value (Figure 2b). In comparison with LR, the N accumulation rate during 2010-13 was 3.3 times higher with HR at 0-15 cm soil depth (Figure 2c). The TN and N-stocks under HR treatment were higher than under LR. This could be attributed to higher N input as residue than in LR (Du et al., 2010). This study shows that the N accumulation increased under HR relative to LR within 2.5 years. This finding is similar to that of Bhattacharyya et al. (2013) who found in Indo-Gangetic Plains that residue retention after all crops in a cotton-maize-wheat rotation for 4 years increased soil TN concentrations and stocks by 16 % relative to residue removal.

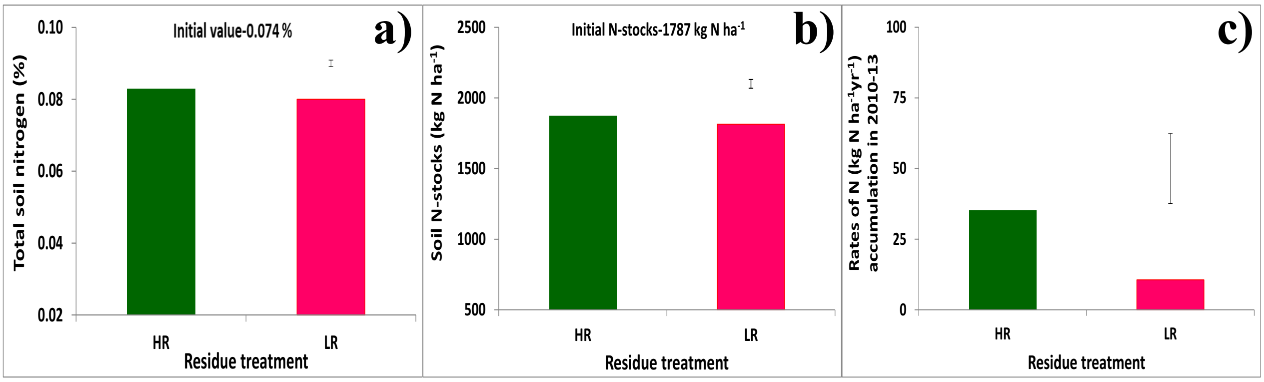

Figure 2. Main effects of residue treatment on total soil N concentrations (a), soil N-stocks (b) in 2012-13 (after Crop 7) and accumulation rate of N rates from 2010-13 (c) at 0-15 cm soil depth. HR=high residue; LR=high residue. The floating error bar indicates the average least significant difference (LSD) at P≤0.05 for the residue treatments. Values are means across residue levels.

N balance

Considering the partial N budget (inputs minus outputs), all treatments except CTHR had a net N loss from 2010 to 2013 (Table 1). The N removal or uptake through grain and straw under SP was 14 % higher than for CT (Table 1). The N loss was also highest in LR relative to HR (Table 1). Based on the N balance (i.e. including changes in soil N-stocks as well as inputs and outputs), SPHR had a small positive N balance while all remaining treatments either had no net change (CTHR) or an apparent loss of N. Nitrogen loss ranged from 319 kg/ha (128 kg/ha/yr) in CTLR to 125 kg/ha (50 kg/ha/yr) in SPLR over the 2.5 year period. However, although inputs of fertilizer and residue N could not match N removal in straw and grain in SPHR, an overall positive N balance was maintained. The negative N balance in CT treatments could be due to greater mineralization of TN and crop residue as a result of increased tillage frequency which might have led to N loss through leaching, volatilization and denitrification (Halvorson et al., 2000, Sainju et al., 2009). These processes were not measured or directly accounted for in this study. Compared to net losses with LR, HR maintained N balance which might be attributed to higher N recycling in crop residues. Hence, the results showed the importance of residue additions, and their N content in maintaining the N balance. Further refinement of the N balance could be achieved by quantifying these potential N loss pathways.

Table 1. Estimated nitrogen balance for the legume-dominated rice-based rotation at Alipur considering residue inputs of eight consecutive crops (seven study crop + one previous rice crop) in 2010-2013. SPHR = strip planting-high residue; SPLR = strip planting-low residue; CTHR = conventional tillage-high residue; CTLR = conventional tillage-low residue

Treatments	SPHR	SPLR	CTHR	CTLR
	kg N/ha			
Soil N-stocks, 2010, initial (A)	1787	1787	1787	1787
Soil N-stocks, 2013, harvest (B)	1979 (±52[a])	1926 (±22)	1771(±53)	1702 (±76)
Change in soil N-stocks (B-A)	192 (±52)	139 (±22)	-17 (±53)	-86 (±76)
N-inputs from crop residue[b] ∑2010-13	209 (±7)	38 (±2)	208 (±5)	36 (±1)
Total N-input from fertilizer, irrigation, rainfall and residue∑ 2010-2013 (C)	533 (±7)	362 (±2)	532 (±5)	360 (±1)
Total removal from grain and straw ∑2010-13 (D)	674 (±86)	625 (±32)	525 (±38)	594 (±55)
N balance, 2010-2013				
Partial N budget (C-D)	-141 (±81)	-263 (±30)	7 (±38)	-234 (±56)
Estimated N balance (B+C-A-D)	51 (±112)	-125 (±47)	-9 (±71)	-319 (±57)

[a] standard error

[b] Values reported for N inputs from rice, mungbean and lentil residue are based on measurement of biomass retained at the time of crop harvest and the measured N concentration in those residues.

Conclusions

The implementation of SP and HR over 2.5 years (short-medium term) in an intensive rice-based cropping system significantly increased TN concentrations, N-stocks and N accumulation of the 0-15 cm soil profile. However, there was a net loss of soil N under CT. The negative N balance of CT was exacerbated by low residue retention which is the current farmer practice. The present results suggested that the increased TN concentrations, N-stocks and N accumulation, and N gain under SP and HR can improve soil productivity and reduce N loss in rice-based cropping systems of Bangladesh. If this is so, then it should be possible to reduce recommended rates of N fertilizer addition in this cropping system, but the amount is yet to be quantified. The present study on a rice-based cropping system needs to be continued for several more years to be able to better conclude on the N dynamics in soil and plants in this system and focus on quantifying N loss pathways. In addition, similar studies elsewhere in this agro-ecosystem and with a cereal-dominant rotation should assess the influence of tillage and residue management on N behavior and crop growth to derive a more general understanding of soil productivity and N balance under CA in the eastern IGP.

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