Title
Nutrient and Residue Management for Improving Productivity and N Use Efficiency of Rice-Wheat-Mungbean Systems in Bangladesh

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Introduction

Land degradation and soil fertility decline are among the main causes of the stagnation and fall of agricultural production in many tropical countries, including those with intensive irrigated cropping systems. Approximately 85% of the area planted with intensive rice-wheat (RW) sequential cropping is found in the Indo-Gangetic Plain (IGP) of South Asia in India, Pakistan, Nepal and Bangladesh (Timsina and Connor 2001). Rice is transplanted in flat fields that are typically ponded for long periods or continuously from transplanting until shortly before harvest. A change from growing crops on the flat to raised beds offers more effective control of irrigation water and drainage. This may be particularly beneficial for non-rice crops grown in rotation with rice, allowing better rainwater management during the monsoon season for rice. Connor et al. (2003) suggested that permanent raised beds might offer farmers further significant advantages such as increased opportunities for crop diversification, mechanical weeding and placement of fertilizers; relay cropping and inter-cropping; and reduced tillage and water saving. There are also indications that crop yields from beds can be further increased by using higher rates of N fertilizer and later irrigation because of the reduced risk of lodging (Sayre and Ramos 1997). Raised beds are increasingly used in many developed and developing countries in mechanized agriculture but have been introduced only recently in Bangladesh, with the aim of improving system productivity (Talukder et al. 2002).

Inclusion of grain legumes in the dry-wet transition of rice-wheat cropping system as a third crop may be another option to increase cropping intensity, soil fertility and productivity of the system. Due to lack of suitable crop establishment practices and temporary water logging at reproductive stage, inclusion of a grain legume like mungbean in the rice-wheat cropping system very often faces problems. Bed planting may be a solution for these problems because raised beds not only facilitates irrigation but also drainage and therein lies their potential to increase the productivity of crops in the system. Growing leguminous crops in a cropping system is beneficial not only for economic products but also for soil amelioration (Singh *et al.* 1993). The common practice of rice to puddle soils destroys the soil physical structure that has implications for the following wheat crop (Hobbs *et al*., 2000**).** Crop residues are an important source of soil organic matter vital for the sustainability of agricultural ecosystems. About 25% of N and P, 50% of S and 75% of K uptake by cereal crops is retained in crop residues, making them valuable nutrient sources (Singh 2003). However, straw retention is not a common practice in the RW systems of Bangladesh, as is the case elsewhere in South Asia. Wheat and rice straw are usually removed from fields for use as cattle feed and for purposes such as livestock bedding, thatching material for houses or for fuel, leaving little for incorporation into the soil. As a result, soil organic matter levels have declined in these cropping systems, and optimization of nutrient uptake and absorption efficiency has become one of the most important goals in crop production strategies.

Thus, crop residue management and raised beds, along with efficient N fertilization strategies, are likely to be key components of new farming practices that can increase and maintain yields from the intensive RW system in Bangladesh. In this paper we report on station research undertaken in north-western Bangladesh to:

- evaluate yields for the intensive multicrop wheat-mungbean-rice sequences on permanent raised beds (PRB) compared with those grown on conventionally tilled systems CTP).
- assess the effect of retention of crop residues on crop performance and soil properties on PRB
- assess N level effects on productivity and estimate N uptake and use efficiency
- evaluate changes in soil properties over time.

Method

A cool season wheat (Triticum aestivum)-spring mungbean (Vigna radiata)-monsoon rice (Oryza sativa) cropping pattern was implemented over 3 years at the Regional Wheat Research Centre, Rajshahi, Bangladesh (24^{o}3'N, 88^{0}41E, 24 m above sea level). Total rainfall was highest during the mungbean and rice seasons and lowest in the wheat season in all years (Figure 1).

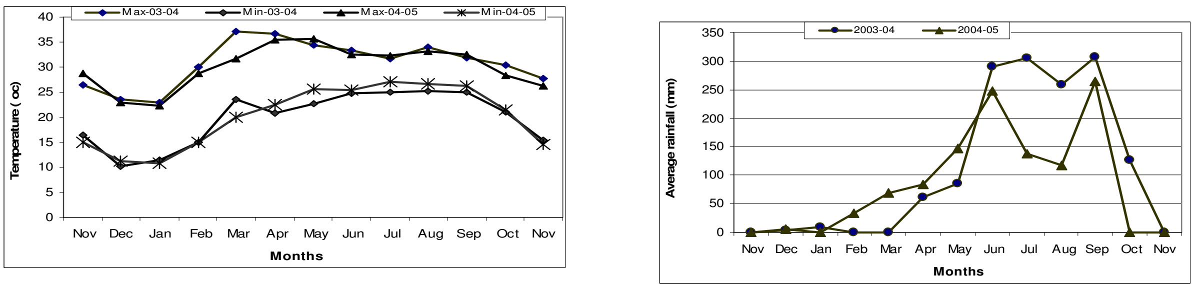

Figure 1. Mean monthly values (3 years, 2004-05 to 2006-07) of rainfall and maximum and minimum temperature at the Regional Wheat Research Centre, Shyampur, Rajshahi, Bangladesh

Mean minimum and maximum temperatures during the rice season (July to November) were 22.6^{0}C and 31.3^{0}C, during the wheat season (November to March) 13^{0}C and 27^{0}C, and for the mungbean season (April to July) 23^{0}C and 33^{0}C. Monthly distribution of rainfall and minimum and maximum temperatures for the experimental period (May 2003 to March 2006) are shown in Figure 1. The soil at the experimental site is a calcareous silty loam with slightly alkalinity (pH 8.0), low organic matter (0.8%) and low nitrogen (mineral N 35 µ/g soil) (BARC, 1997).

The trial involved a three-crop (rice-wheat-mungbean rotation planted on raised beds or cultivated flat land. Rice was transplanted (one 15-days-old seedling per hill) with hill-to-hill spacing of 15 cm and line-to-line spacing on the beds of 30 cm in late July and harvested in late November by hand. Wheat was planted at the nationally recommended seeding rate of 100 and 120 kg/ha for beds and for conventional till on the flat, respectively, in late November and harvested in late March. After harvest of wheat, mungbean (Vigna radiata) was planted in early April at the same time at the nationally recommended seeding rate of 35 kg/ha for mungbean and harvested in mid July for both beds and conventional till on the flat. The trial was originally established as a PRB experiment with two straw management practices (main plots-100% straw retention (SR) and 0% SR) and five N levels (subplots -0%, 50%, 100%, 150% and 200% of recommended). The area of each subplot was 15 m^2 (5m x 3m). After completion of two crop cycles (2003 wheat to 2004 wheat), the experiment was modified by the introduction of conventional tillage on the flat with no straw retention (CTP + 0% SR). Thus, the modified experiment consisted of 20 subplots with four tillage/straw treatments (100% SR + PRB, 100% SR + CTP, 0% SR + PRB and 0% SR + CTP) and five N levels (0%, 50%, 100%, 150% and 200% of recommended) with three replicates. After harvesting and threshing, the rice and wheat straw were returned without chopping following planting of the wheat or rice, as surface mulch to the respective plots.

The width of the beds was 60 cm (furrow to furrow) and the depth of the furrows on average was 12.5 cm. Two rows of wheat (var. Shatabdi) or rice (var. BRRI Dhan 39) with a spacing of 30 cm, were planted by hand sowing/transplanting on the beds. Mungbean (var. BARI Mungbean-6) was sown by the bed former in the furrows between the beds. The mungbean was harvested about 60 days after sowing. In CTP, wheat, rice and mungbean were planted in 20 cm, 30 x 15 cm (row x plant) and 30cm rows, respectively. A basal dose of P (20, 22 and 26 kg/ha) from triple super phosphate, K (15, 35 and 33 kg/ha) from muriate of potash and S (10, 11 and 20 kg/ha) from gypsum was applied to mungbean, rice and wheat, respectively. In rice the entire amount of P-K-S was broadcast before transplanting with straw retention for both PRB and CTP. For CTP the fertilizer was broadcast before tillage. The recommended rate of N (80 kg/ha for rice, 100 kg/ha for wheat and 20 kg/ha for mungbean) was applied as urea. For mungbean all N was applied before seeding. With CTP rice, N was broadcast, while with beds it was banded on top of the bed between two rows in three equal installments 15, 30 and 45 days after transplanting. With wheat, two-thirds of the N was applied before seeding and the remaining one-third at crown root initiation (CRI) (Zadoks growth stage 1.3).

Sufficient irrigation water was applied to fill the furrows between the raised beds. The wheat received three irrigations-at CRI, booting and grain-fill stages. For rice, irrigation water was applied for CTP with approximately 4 cm of irrigation and then re-irrigation when the soil was near saturation. Generally, both CTP and PRB were irrigated on the same days, but less water was needed to fill the furrows with PRB compared to CTP. Mungbean received pre-sowing irrigation to enhance germination. Chemical weed control in all crops was administered 1 or 2 days before planting. Grain and straw yield were determined on a 7.5 m^2 area in the centre of each plot. Samples were dried in a hot-air oven at 72^0C for 3 days.

The N content of grain and straw sub-samples of all three crops was determined by the micro-Kjeldahl method. After rice harvest, soil samples were collected from 0-30 cm depth from three sites in both the bed tops and furrows, and from three sites in each CTP plot using a 6-cm diameter auger for the determination of nutrients.

Total system productivity

Total system productivity (TSP) was calculated using the method of Tanaka (1983). **Total system productivity** (TSP) for each treatment was calculated as the total annual productivity (or the annual total of economic yield of the individual crops) based on equivalent yields (1.35, 1.39 and 1.54, respectively, for rice, wheat and mungbean). TSP (rice-wheat-mungbean) = (rice grain yield*1.35) + (wheat grain yield*1.39) + (mungbean grain yield*1.54)

Estimation of nitrogen uptake

The result was expressed in percentage. N-uptake by grain and straw also were calculated by the following formulae

$$\text{N-uptake by grain (kg ha}^{-1}\text{)} = \frac{\text{Total N (\%) in grain} \times \text{grain yield (kg ha}^{-1}\text{)}}{100}$$

$$\text{N-uptake by straw (kg ha}^{-1}\text{)} = \frac{\text{Total N (\%) in straw x straw yield (kg ha}^{-1}\text{)}}{100}$$

Different measures of nitrogen use efficiency

The different measures of N-use efficiencies; physiological efficiency (PE), fertilizer recovery efficiency (RE), and agronomic efficiency (AE) were calculated as described by Dobermann and Fairhurst (2000). Total N uptake as used in this term referred to N uptake by above ground biomass (grain and straw) only.

Recovery efficiency (RE) of added N was

Agronomic efficiency (AE) of added N was calculated as

$$\text{RE (\%)} = \frac{\text{Total N uptake (kg N ha}^{-1}\text{) of the treatment- total N uptake (kg N ha}^{-1}\text{) of the control}}{\text{Applied N (kg N ha}^{-1}\text{) of the treatment}} \times 100$$

calculated as

$$\text{PE(kg grain kg}^{-1}\text{ N uptake)} = \frac{\text{Grain yield (kg ha}^{-1}\text{) of the treatment – grain yield (kg ha}^{-1}\text{) of the control}}{\text{Total N uptake (kg N ha}^{-1}\text{) of the treatment – total N uptake (kg N ha}^{-1}\text{) of the control}}$$

Agronomic efficiency (AE) of added N was calculated as

$$\text{AE(kg grain kg}^{-1}\text{ N applied)} = \frac{\text{Grain yield (kg ha}^{-1}\text{) of the treatment – grain yield (kg ha}^{-1}\text{) of the control}}{\text{Applied N (kg N ha}^{-1}\text{) of the treatment}}$$

Statistical analysis of data

C and Microsoft Excel and DMRT was used to determine the significant difference between treatments. Simple correlation was determined following the computer package SPSS. Treatment means were compared using Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

Multiple Range Test (DMRT) (Gomez and Gomez, 1984). The data were analyzed statistically following computer package MSTAT- All the data were statistically analyzed following the ANOVA technique and the significance of mean differences was adjusted by Duncan's

Results and discussion

Total system productivity

Commonly, conversion from conventional tillage to reduced-till systems with straw retention requires several crop cycles before potential advantages or disadvantages become apparent (Phillips and Phillips 1984). In our experiment straw retention increased productivity rapidly, starting from the second crop cycle. We believe this is an important finding because, if repeated on farmers' fields, farmers will quickly realize the benefits and be more interested in adopting the technology. Total system productivity increased by 10-12% in 100% straw retention (SR) level with permanent bed planting system over flat/conventional (Fig.2). Total system productivity of rice, wheat and mungbean (R-W-M) was 12 tha^{-1}/yr^{-1} Figure 2 presents the system yields on different tillage options and straw retention from 2004-05 to 2006-07. For all crops the highest system yields occurred in PRB + 100% SR. Yields on PRB consistently increased as SR increased from 0% to 100%, but the differences between 0% and 100% SR were always significant for the three crops. Lower system productivity also occurred from 0% SR with CTP due to reduced crop growth. Yields tended to be lower in with lower levels of straw retention for all crops. Similar observations were made by Sayre et al. (2005) in Mexico.

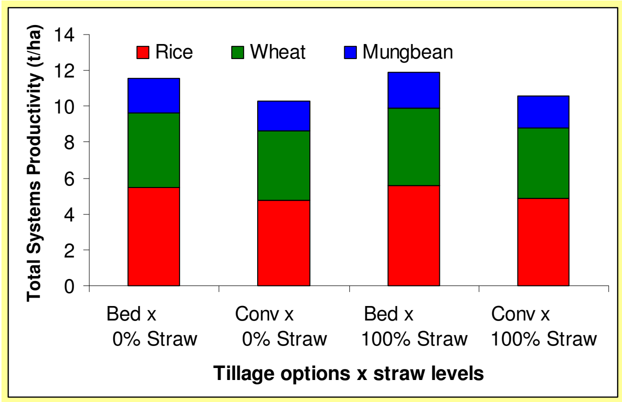

Fig 2: Total system productivity under tillage options and straw levels in rice-wheat-mungbean systems

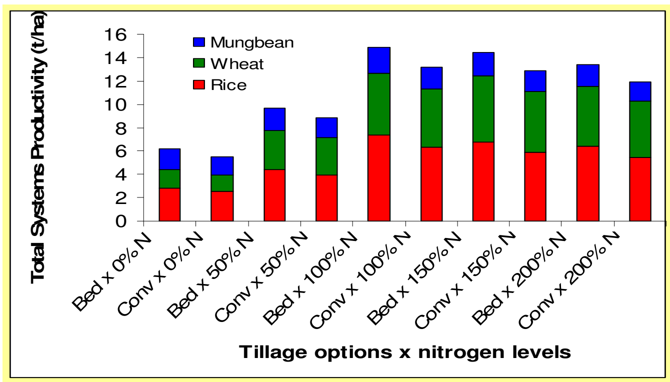

Fig. 3: Total system productivity under tillage options nitrogen levels in rice-wheat-mungbean systems

Total system productivity significantly increased by 11% in rice, 14% in mungbean with increasing N level up to 100%; and by 16% in wheat up to 150% N level with PB systems (Fig. 3).

Figure 3 presents the system yields or productivity on different tillage options and nitrogen levels from 2004-05 to 2006-07. For all crops the highest system productivity occurred in PRB with150% N (150 kg N/ha in wheat) 100% N both in rice and mungbean (80 kg N/ha in rice, 20 kg N/ha in mungbean). Yields and productivity on PRB consistently increased as N rates increased from 0% to 100% both in rice and mungbean, but the differences between 0% and 150% in wheat were significant. Lower system productivity also occurred from 0% N with CTP due to less N uptake and use efficiency. Yields tended to be lower for differences in nitrogen levels for all crops. Similar observations were made by Yadvinder Singh et al. (2006) in India. Yields tended to be smaller in differences at the four N levels in wheat, at three N levels in rice and at two lower N levels in mungbean (Fig. 3). Averaged over the 3 years, PRB + 100% SR with 100% N gave a 17% increase in wheat yield over PRB + 0% SR at the same N rate (Fig. 3), but there was no significant mungbean yield increase with additional N with 100% SR, However, yield of PRB + 100% SR with 150% N was significantly higher than PRB + 0% SR with 100% N. Average rice yield on PRB + 100% SR with 50% N was significantly higher than with 0% SR at the same N rate, and there was no further yield increase at higher N rates. Rice yield declined with 100% SR at the two highest N rates, mostly due to lodging.

Maximum average wheat grain yield was obtained on PRB with 150% N and 100% SR, 17% higher than on PRB + 0% SR (Fig. 3). These yield increases with straw retention are probably due to suppression of soil evaporation, less weeds and more efficient use of fertilizers. Limon-

Ortega et al. (2000), reported that with PRB both wheat and maize yields responded to higher rates of N fertilizer.

Wheat and rice yields were comparatively low under the CTP system due to water logging and the resultant acute weed stress (poor crop growth could not compete as well with weeds) in early as well as late growth stages. Variability in wheat yields in Bangladesh is mostly the result of the high temperature that can occur during the grain filling phase, especially for late-sown crops (Midmore et al. 1984). Additionally, growers are now reluctant to grow wheat because heavy pre-monsoon rain and strong winds prior to harvest make it more vulnerable and risky. The introduction of zero tillage, with or without PRB, will help because the crop can be planted earlier, reducing the risk of early storms before maturity.

Nitrogen uptake and use efficiency

Total N uptake increased with increasing up to 150% and it was similar as 200% in all crops.

The increased N uptake for PRB was 12% in rice, 19% in wheat and 9% in mungbean over plots (Figure 4). Nitrogen uptake was significantly ($P<0.5$) influenced by straw retention and N level. In PRB+100% SR plots, total N uptake by rice was maximum at 50-100% N, by wheat at 100-150% N and by mungbean was 50-100% N. In contrast, in both PRB and CTP without straw retention, there was a consistent trend for increasing N uptake up to 150% N rate in all crops. Limon-Ortega et al. (2000) also observed that permanent beds with straw retention gave the highest average wheat grain yields (5057 t/ha), N use efficiency (28.2 kg grain/kg of N supply) and total N uptake (133 kg/ha).

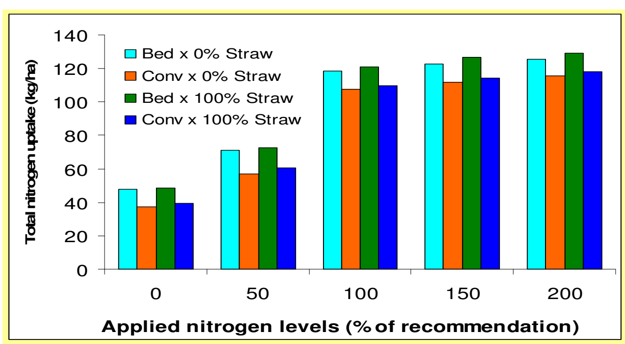

Fig. 4: Total nitrogen uptake under tillage options, straw and nitrogen levels in rice-wheat-mungbean systems

N use efficiency (calculated PE, AE and RE) decreased as N rate increased in all treatments (Table 1). At the lowest N rate there was a consistent trend for higher AE on PRB with 100% SR and 0% SR. There was a consistent trend for higher PE on PRB as the amount of SR increased from 0% to 100% across all crops. Similar observations were made by Yadvinder-Singh et al. (2004). They reported that AE was significantly higher in straw retained + green manure cultivated treatments than other treatments for wheat. The availability of N and its uptake and utilization by CTP (Fig.4). Retention of straw resulted in increased N uptake in both N fertilized and zero N crops are closely related to system productivity, but are controlled by numerous abiotic and biotic factors in the soil-plant system. These include cultivar, fertilizer input, weather, pests, and management of soil, crop residues, irrigation and drainage (Dobermann Yadvinder-Singh *et al.* 2005). Given the complexity of the RW cropping system associated with the pronounced anaerobic-aerobic cycles, and important question concerns how N use efficiency can be improved. Good N management and straw retention in a PRB system may allow this. Compared to other parts of the IGP, such as the Punjab, our Rajshahi site received far more spring and summer rainfall (1,415-1,962 mm from May to August during the 3 years) in the mungbean and rice seasons (Fig1) and has a higher shallow water table (only 80-90 cm depth). The result is a much wetter upper soil profile that is favorable for rice growth. It also helps the decomposition of retained straw, resulting in a higher uptake of nutrients and more efficient use of water. N use efficiencies increases rice life 3-5 days.

Table 1: Nitrogen use efficiency of rice, wheat and mungbean (2004-05 to 2006-07) as influenced by straw retention, tillage and N level at Rajshahi, Bangladesh.

Treatment		AE(kg grain kg $^{-1}$N applied)			PE(kg grain kg $^{-1}$N uptake)			RE (%)		
		Rice	Wheat	Mungbean	Rice	Wheat	Mungbean	Rice	Wheat	Mungbean
100% SR + PRB										
	N_0	-	-	-	64.5	44.5	49.5	-	-	-
	N_{50}	49.3	33.5	16.5	53.4	33.5	36.8	95.4	96.8	112.7
	N_{100}	41.2	24.3	10.6	45.8	26.2	32.3	89.8	81.7	106.3
	N_{150}	23.5	18.5	6.7	41.4	25.7	25.3	66.2	64.7	95.7
	N_{200}	20.2	14.5	3.9	38.2	23.4	22.4	50.9	45.2	77.6
0% SR + PRB										
	N_0	-	-	-	58.3	39.5	43.5	-	-	-
	N_{50}	42.3	28.3	12.8	49.8	29.5	31.5	87.8	84.5	95.3
	N_{100}	34.5	21.5	9.7	41.5	22.4	27.3	78.6	74.6	87.3
	N_{150}	21.3	14.3	6.3	38.9	18.5	22.5	58.6	62.5	82.1
	N_{200}	18.5	10.5	3.2	29.6	11.5	18.3	42.5	53.2	63.2
100% SR + CTP										
	N_0	-	-	-	59.6	44.5	44.5	-	-	-
	N_{50}	45.3	29.5	14.5	50.2	34.2	32.4	90.2	87.3	98.6
	N_{100}	38.5	22.3	10.2	43.2	25.3	28.3	82.3	77.3	89.3
	N_{150}	25.4	19.3	6.4	37.8	22.3	23.2	60.5	65.3	82.5
	N_{200}	20.3	12.4	3.4	30.5	13.5	19.7	44.5	53.4	68.5
0% SR + CTP										
	N_0	-	-	-	52.3	45.3	57.6	-	-	-
	N_{50}	38.7	24.1	12.6	49.6	33.7	43.5	82.7	81.3	97.2
	N_{100}	33.4	20.4	9.6	42.2	27.9	34.5	71.4	71.2	81.4
	N_{150}	19.2	16.2	6.4	37.5	26.8	30.9	48.9	59.6	71.6
	N_{200}	14.7	9.9	2.6	33.2	24.8	24.3	39.2	44.3	58.5

PRB = permanent raised beds, SR = straw retention; CTP = conventional tillage practice

Soil organic matter (SOM)

After 3 years (2003-04 to 2005-06), retention of straw from all three crops in the zero-till PRB system had increased the soil organic matter by 0.22% (Table 2). While some of the increase may have been due to formation of the beds from topsoil, the change in organic C increased as the rate of residue retention increased from 100%, indicating that straw retention also affected organic C on the beds. 100% SR with PRB, P and Zn availability increased. At low N levels (0% and 50% of recommended) there appeared to be a slight decline in soil organic C. After 3 years of CTP without residues, soil organic C had decreased by a few per cent at all N rates and there was a consistent trend for a larger decline at the lower N rate. The increase in soil organic C with 100% SR at 50-150% N was almost double that with 0% N. Kumar and Goh (2000) reported that, in the longer term, residues and untilled roots from crops can contribute to the formation of SOM. It seems clear that further increases in the productivity of the RW system will depend on improvements in soil fertility through proper management and use of crop residues and other agricultural wastes. After the four RWM crop cycles, the soil color had darkened, presumably due to the build-up of organic matter in the topsoil (Figure 5).

Table 2: Chemical changes in soil under residue retention with tillage options

Parameters	Bed x 0% Straw	Conv x 0% Straw	Bed x 100% Straw	Conv x 100% Straw
pH	8.2	8.3	8.3	8.3
OM (%)	1.16	1.12	1.38	1.29
Total N (%)	0.11	0.12	0.09	0.11
P (mg/g soil)	15.12	14.5	17.89	14.56
K ml (eq/100 g soil)	0.37	0.39	0.32	0.30
S (mg/g soil)	17.25	24.2	15.85	21.27
Zn (mg/g soil)	0.23	0.12	0.37	0.17
B (mg/g soil)	0.31	0.21	0.35	0.24
EC (dS/m)	0.97	1.24	0.92	1.17

Summary and Conclusions

Retention of 100% crop residues together with zero-till permanent raised bed seeding systems offer an important soil restorative management strategy likely to have a long-term positive impact on soil quality and crop productivity in intensive rice-wheat-mungbean (RWM) cropping systems in Bangladesh. Lignified residual straw and roots added more organic matter and nutrients into the soils under PRB, resulting in increased nutrient uptake by the crops. Crop productivity on beds with 100% straw retention rose by about 7% for rice, 12% for wheat and 16% for mungbean at 100% N rates over a 3 year cycle of the RWM cropping pattern compared with 0% SR+PRB at the same N rate. When compared with the farmers' conventional tillage practice, crop productivity with PRB improved (?) 50% for rice, wheat and mungbean crops, respectively, at 100% N rates over a 3 year cycle of the RWM cropping pattern. Yield in N unfertilized rice, wheat and mungbean increased when straw was retained and this appeared to be due to an increased uptake of N. This increase in soil N supply led to a reduction in N use efficiency in the N-fertilized plots, suggesting that N fertilizer application rates can be reduced when straw is retained. Retention of crop residues as a surface mulch reduced moisture depletion and increased SOM content over relatively short periods of time. Fertilizer use efficiency may be increased by implementing permanent raised bed management in addition to reducing weed and crop lodging problems. Permanent raised beds will also help ameliorate the adverse effects of tillage on soil structure, which lead to water logging under excess water conditions and hamper establishment, growth and development of most crops including mungbean. The use of PRB reduced the overall cost of production and the long turnaround time between crops with CTP (data not presented). Thus, our results showed that PRB with straw retention can help to sustain and intensify RW systems to RWM systems with proper management in Bangladesh. Further on farm adaptive research with farmers now appears warranted.

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