

Research Article

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Productivity, nutrient balance, and economics of monsoon rice under different nutrient management practices in two agro-ecological zones of Bangladesh

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Abstract: Inherently poor soil fertility and non-adoption of fertilizer recommendations based on soil test and yield targets by farmers limit the productivity and profitability from monsoon rice in Bangladesh and much of South Asia. In the Level Barind Tract (LBT; AEZ-25) and the High Ganges River Floodplain (HGR; AEZ-11) agro-ecological zones (AEZs) of Bangladesh, monsoon (aman/kharif) season transplanted rainfed rice (known as T. aman rice) is grown in large areas after maize, wheat and/or mungbeans, with residues of each crop removed from the field after grain harvest. This results in lower grain yield and lower profits in these AEZs as compared with other AEZs. Nutrient management, based on soil test, yield targets, or integrated use of inorganics and organics for each AEZ together with

retention of crop residue, has the potential to increase rice yield, reduce production cost and increase income. With this hypothesis, this study was conducted to determine the optimum nutrient management practices for achieving higher yield, maintaining apparent soil nutrient balance, and obtaining high profits from monsoon rice. Twelve nutrient management options were evaluated, of which the first six were: (i) 80-16-44-12-2 kg ha⁻¹ of N, P, K, S, Zn respectively for a high yield goal (T₁; ‘HYG’); (ii) 56-12-32-8-1.5 kg ha⁻¹ respectively for a medium yield goal (T₂; ‘MYG’); (iii) 65-13-32-9-2 kg ha⁻¹ respectively plus 5 t ha⁻¹ cowdung as integrated plant nutrient management system (T₃; ‘IPNS’); (iv) 67-14-41-9-2 kg ha⁻¹ respectively as a soil test-based fertilizer management strategy (T₄; ‘STB’); (v) 40-9-11-0-0 kg ha⁻¹ respectively as per farmers’ practice (T₅; ‘FP’) and (vi) 0-0-0-0-0 kg ha⁻¹ as a control (T₆; ‘CON’). The remaining six treatments were the same as above but each also included the crop residue incorporation (CRI), i.e., (vii) T₇, ‘HYG+CRI’; (viii) T₈, ‘MYG+CRI’; (ix) T₉, ‘IPNS+CRI’; (x) T₁₀, ‘STB+CRI’; (xi) T₁₁, ‘FP+CRI’; and (xii) T₁₂, ‘CON+CRI’. In both AEZs, STB plus CRI resulted in the highest rice yield (p≤0.05) followed by ‘STB’ and ‘IPNS+CRI’. In comparison with ‘FP’ and ‘CON’, each without CRI, balances were positive (p≤0.05) for P, S, Zn and B but were negative for N and K in ‘HYG’, ‘MYG’, ‘IPNS’ and ‘STB’ with or without CRI. In both AEZs, STB nutrient management had the highest (p≤0.05) net returns (526 & 487 US\$ ha⁻¹, respectively), highest benefit cost ratio (BCR; 3.54 & 3.36) and highest marginal benefit cost ratio (MBCR; 10.47 & 10.19). These were followed by STB+CRI and ‘IPNS’, while they were lowest (p≤0.05) for CON and FP. We recommend that nutrient application, based on soil test with incorporation of mungbean residue, followed by IPNS, could be the best strategies for achieving high yield, improving soil fertility and for fetching a higher profit from monsoon rice in Bangladesh and similar soils and growing environments of South Asia.

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1 Introduction

Rainfed monsoon rice is the most important crop to feed the ever-growing population in South Asia and South-East Asia. While there is limited scope for expanding the cultivated area under cropping in South Asia, including Bangladesh, intensification of land for crop production and increase in crop productivity could help meet the food demand of an increasing population (Dobermann et al. 2003a,b; Timsina et al. 2011 2018). In Bangladesh, depending on the ecological condition of a given agro-ecological zone (AEZ) and the traditional farming, rice is grown in a range of cropping systems from mono-cropping to multiple-cropping (Timsina and Connor 2001; Jahan et al. 2016; Hossain et al. 2016). Chemical fertilizers are an essential component of modern crop production systems (Timsina 2018), with about 50% of the world's crop production being attributed to chemical fertilizer use. However, crop production, aiming at high yield and soil sustainability, cannot be achieved with the exclusive use of chemical fertilizers alone (Hossain et al. 2016; Noor 2017). Hence, for crop production to be sustainable, balanced amounts of nutrients through inorganic and organic sources need to be applied to replenish the nutrients removed by the crop (Timsina and Connor 2001; Dobermann et al. 2003a,b; Dobermann et al. 2013; Timsina 2018).

Higher rice yields, on a sustainable basis, can only be harvested through balanced and integrated management of nutrients. Soil test-based fertilizer application, to achieve target yield, can help overcome the problem of nutrient mining from soils (Jahan et al. 2016; Hossain et al. 2016; Alam et al. 2017). Nonetheless, intensive cropping with modern varieties, for example, three rice crops per year, induces micronutrient deficiency in soils due to uptake by plants and leaching by monsoon rains and irrigation (Jahan et al. 2016). This risk can be attenuated by the addition of organic manures (Baruah and Baruah 2015; Jahan et al. 2016) and incorporating crop residues (Devi et al. 2017) as well as inclusion of legumes in rotation, without any yield penalty (Hua et al. 2015; Hossain et al. 2016). Integrated use of organic manures, in combination with chemical fertilizers, can help increase soil fertility (Jahan et al. 2016; Alam et al. 2017; Timsina

2018). Application of nutrients, using either organic and/or inorganic sources, to the preceding crop, can have a residual effect on the subsequent crop (Dobermann et al. 2003a,b; Dobermann et al. 2013; Sapkota et al. 2015; Timsina et al. 2006a, b). Therefore, while making fertilizer recommendations, residual effect of inorganic and organic sources of fertilizers or manures should be considered.

In the Level Barind Tract (LBT; AEZ -25) and the High Ganges River Floodplain (HGR; AEZ-11) of Bangladesh, transplanted rainfed rice, grown in the monsoon season, which is also called aman or kharif season (thus known as T. aman rice), is the most popular crop. However, the yield of rainfed monsoon rice in the HGR and LBT of Bangladesh is lower than other parts of the country as farmers generally apply fertilizers to the preceding non-rice crops and apply very little or none to rice. It can be hypothesized that, due to differences in soils and climate and farmers' varying fertilizer management practices, fertilizer rates for rice would differ for the two AEZs. Thus, it is imperative to develop fertilizer management practices for rice for each AEZ considering the inherent soil fertility status, crops and cropping systems practiced, and whether the residues of the previous crops, either legumes or non-legumes, are applied to rice or not.

Integrated nutrient management strategies may, thus, be adopted for the sustainable production of monsoon rice. Development of site-specific (AEZ-based) nutrient recommendations to achieve target yield and high profits from monsoon rice without declining the soil fertility would probably be the best fertilizer management practice in rice. This study was, therefore, conducted to determine the nutrient management practices for obtaining higher rice yields and economic returns, without declining the soil nutrient balance, for monsoon rice in Bangladesh and similar rice-growing environments in South Asia and SE Asia.

2 Materials and methods

2.1 Site description

2.1.1 Locations and morphological characteristics of the experiment sites

The research was conducted during two consecutive growing seasons in two agro-ecological zones (AEZs) of Bangladesh viz. (a) Level Barind Tract (AEZ -25) (Agricultural Research Station (24° 50' 30.27'' N, 89° 21' 54.30'' E and 22.56 meters above sea level (masl)), Seujari-Bogra, and (b) High Ganges River Floodplain

(AEZ-11) (Regional Agricultural Research Station (23° 11' 13.03'' N, 89° 11' 54.30'' E and 10.67 masl), Khaertala-Jashore (FRG 2012). In AEZ 25, topography is medium high land with dark grey terrace soil without good drainage capacity. The soil of AEZ-11 is similar to AEZ-25 except being a dark grey floodplain soil, which is calcareous in nature (FRG 2012).

Initial soil properties and weather characteristics during crop growing period

The initial physico-chemical properties of the experimental soils (0–15 cm in depth), for the two AEZs, are given in Table 1. The climate of both AEZs is subtropical monsoon type with total annual rainfall of 1668 and 1595 mm at Bogra (AEZ-25) and Jashore (AEZ-11), respectively, of which 90-95% of the rain was received during the rice season from July to October (Figure 1). Relative humidity in

both locations was 85-90% during the rice growing period (July to October). Monthly average maximum temperature was 35-36°C in May at both the locations, while monthly average minimum temperature ranged from 10°C to 11°C in January (Figure 1). Thus, the two AEZs differed in climate and soil types.

2.2 Experimental design, treatments and residue management

There were twelve nutrient management treatments in this study (Table 2). The first six treatments consisted of nitrogen (N), phosphorus (P), potassium (K), sulfur (S) and zinc (Zn) applied at various rates: (1) @ 80-16-44-12-2 kg ha⁻¹ N, P, K, S and Zn respectively for high yield goal

Table 1: Initial soil fertility status of experimental soils in two locations of Bangladesh (AEZ-25: Bogra; AEZ-11: Jashore)

| Locations | pH | OM (%) | Total N (%) | Available P (µg g ⁻¹) | Exchangeable K (meq100 g ⁻¹) | Available S (µg g ⁻¹) | Available Zn (µg g ⁻¹) | Available B (µg g ⁻¹) |
|-----------|-------|--------|-------------|-----------------------------------|--|-----------------------------------|------------------------------------|-----------------------------------|
| AEZ-25 | 5.21 | 1.14 | 0.058 | 4.67 | 0.12 | 7.17 | 0.48 | 0.29 |
| | St. A | L | VL | VL | L | VL | L | L |
| AEZ-11 | 7.02 | 1.21 | 0.063 | 6.56 | 0.12 | 8.64 | 0.96 | 0.21 |
| | N | L | VL | VL | L | L | M | L |

OM- Organic Matter, St. A- Strongly Acidic, N- Neutral, M- Medium, L- Low, VL- Very Low.

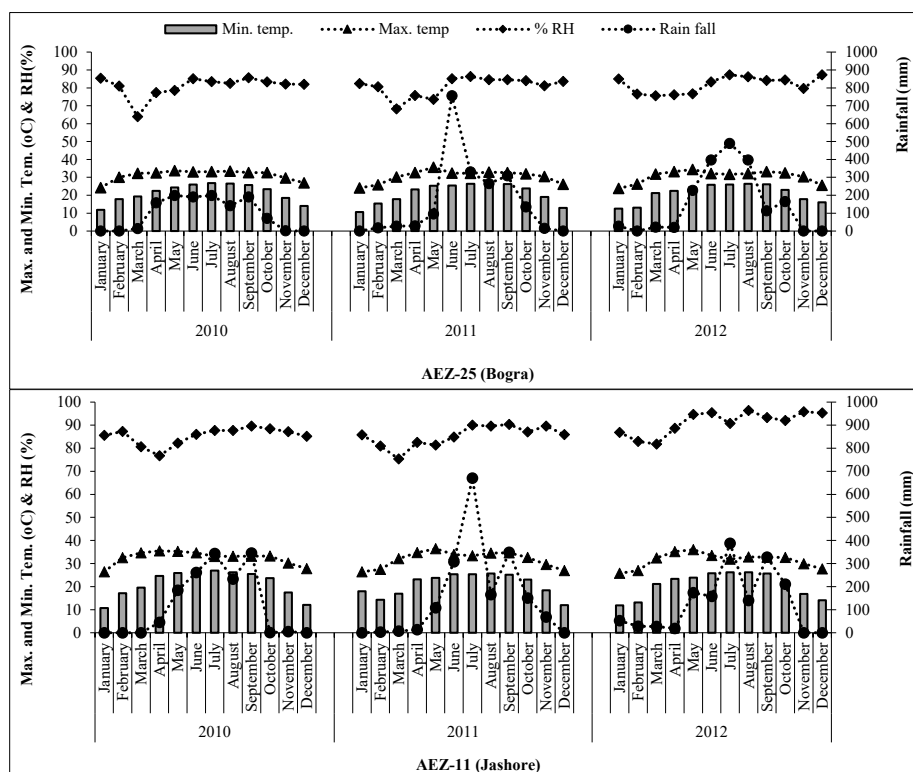


Figure 1: Weather information during rice growing season during 2010 to 2012 in Bogra (AEZ-25) and Jashore (AEZ-11) sites in Bangladesh

Table 2: Treatment details for 12 treatments (6 without and 6 with CRI) for two locations of Bangladesh

| Locations | Treatments* | CD (t ha ⁻¹) | N | P | K | S | Zn |
|---------------------|-------------|-----------------------------|------------------------|-----|----|-----|-----|
| | | | (kg ha ⁻¹) | | | | |
| Bogra (AEZ-25) | HYG | 0 | 80 | 16 | 44 | 12 | 2.0 |
| | MYG | 0 | 56 | 12 | 32 | 8.0 | 1.5 |
| | IPNS | 5 | 65 | 13 | 32 | 9.0 | 2.0 |
| | STB | 0 | 67 | 14 | 41 | 9.0 | 2.0 |
| | FP | 0 | 40 | 9.0 | 11 | 00 | 00 |
| | CON | 0 | 00 | 00 | 00 | 00 | 00 |
| Jashore (AEZ-11) | HYG | 0 | 80 | 16 | 44 | 12 | 2.0 |
| | MYG | 0 | 56 | 12 | 32 | 8.0 | 1.5 |
| | IPNS | 5 | 65 | 13 | 32 | 9.0 | 2.0 |
| | STB | 0 | 66 | 13 | 41 | 12 | 2.0 |
| | FP | 0 | 41 | 8.0 | 13 | 00 | 00 |
| | CON | 0 | 00 | 00 | 00 | 00 | 00 |

*HYG'; High Yield Goal, 'MYG'; Moderate Yield Goal, 'IPNS'; Integrated Plant Nutrient System, 'STB'; Soil Test Based, 'FP'; Farmer's Practice, 'CON'; without fertilizers; CD; Cow dung; CRI; crop residue incorporation.

*All the above six treatments at each AEZ also included CRI thus making total of 12 treatments in each AEZ.

(T₁; 'HYG'); (2) @ 56-12-32-8-1.5 kg ha⁻¹ respectively for medium yield goal (T₂; 'MYG'); (3) @ 65-13-32-9-2 kg ha⁻¹ respectively plus 5 t ha⁻¹ cowdung as integrated plant nutrient management system (T₃; 'IPNS'); (4) @ 67-14-41-9-2 kg ha⁻¹ respectively as soil test-based fertilizer management (T₄; 'STB'); (5) @ 40-9-11-0-0 kg ha⁻¹ respectively as farmers' practice (T₅; 'FP') and (6) 0-0-0-0-0 kg ha⁻¹ as control (T₆; 'CON'). The remaining six treatments were the same as above, but each also had crop residue incorporation (CRI), i.e., (T₇; 'HYG+CRI'; T₈; 'MYG+CRI'; T₉; 'IPNS+CRI'; T₁₀; 'STB+CRI'; T₁₁; 'FP+CRI'; T₁₂; 'CON+CRI'). For IPNS, the recommended dose of cowdung (5 t ha⁻¹) supplied 25 kg N, 7.5 kg P, 12.5 kg K and 10 kg S considering 0.5% N, 0.15% P, 0.25% K and 0.20% S in it (FRG, 2012). Thus, the total nutrient rates in IPNS were 90 kg N, 20.5 kg P, 44.5 kg K, 19 kg S and 2 kg Zn. Fertilizer rates for FP were determined based on data collected after interviewing 30 farmers from the adjacent areas to the experimental sites in each AEZ. Based on the residue dry weight and its nutrient content, mungbean residues yielded about 7-18 kg N, 2-5 kg P, 8-17 kg K, 2-5 kg S, 0.02-0.06 kg Zn, and 0.02-0.05 kg B/ha in the treatments that included CRI. The twelve treatments in each AEZ were arranged in a randomized complete block design with three replications.

Prior to the start of the experiment, farmers grew a partially-irrigated wheat crop with moderate amounts of

N, P and K, but no S or Zn, and didn't apply any cowdung or other organic fertilizers. Thus, there was very negligible or little residual effect of fertilizers from wheat to the ensuing mungbean or rice crops. Before the planting of rainfed rice in the experiment, fallow plots were maintained for the first six treatments without CRI (mungbean residue incorporation) while mungbean was grown for the second six treatments with CRI. After the mungbean harvest, its residues were incorporated in the CRI plots. The nutrient management and crop residues incorporation procedures have been provided in detail elsewhere (Jahan et al. 2014a, b, 2016).

2.3 Experimental detail and crop management

2.3.1 Variety, sowing time, and crop management

Thirty-day old rice (var. 'BRRI dhan 39') seedlings (three seedlings hill⁻¹) were transplanted on 5 and 7 July in 2011 and 2012, respectively, following a planting geometry of 20 cm × 15 cm. N, P, K, S, Zn and B were applied through urea, triple super phosphate (TSP), muriate of potash (MP), gypsum, zinc sulphate and boric acid, respectively. N was applied into three equal splits at 15, 30 and 45 days after transplanting (DAT) while all of P, K, S and Zn were

applied basally. Weeding, irrigation and pest control measures were carried out as and when needed.

2.4 Data collection and processing

2.4.1 Crop data

For recording different observations, the rice crop was harvested on October 25 and October 31 during 2011 and 2012, respectively. For yield estimation, plants were harvested from 2 m × 0.5 m area (2 m long, 25 middle rows) at maturity from the central rows to avoid the border effects. The harvested samples from each plot were bundled and tagged, followed by thoroughly drying under bright sunshine until they were fully dried and then threshed.

Plant height (cm) of 10 randomly selected plants from each plot was measured with a meter rod. The number of productive tillers m² was counted in five 1 m long rows, while the number of grains panicle⁻¹ and number of sterile spikelets panicle⁻¹ were recorded from 10 randomly selected panicles, and then averaged. Grain yield and 1000-grain weight were adjusted to 14% moisture content according to Hellevang (1995).

2.4.2 Nutrients in plants and soils, and soil nutrient balance

Procedures for analysis of the plant and soil samples are described elsewhere (Jahan *et al.* 2014a, b, 2016; Hossain *et al.* 2016). The apparent nutrient balances (P, K, S, Zn and B) were estimated following standard procedures (FRG 2012; Jahan *et al.* 2014a, b, 2016). The nutrient inputs, through crop residues, were also considered.

2.5 Statistical analysis

Significance of treatment effects on the yield and yield attributes, as well as on the soil nutrient balances and uptake for each year in each AEZ, were determined separately by analysis of variance (ANOVA) of the RCBD. Treatment means were separated by Duncan's Multiple Range Test (DMRT) using the Statistical Package R at 5% level of significance (R Core Team 2013).

2.6 Economic analysis

For the computation of economic analysis, the costs required for land preparation, bed preparation, labour, seed, pesticides, irrigation and other factors were considered as fixed costs. The prices of nutrients added through organic, inorganic and crop residues were considered to be the variable costs. The farm gate prices of products were collected from local farmers and markets to compute gross return, gross margin, net returns, benefit cost ratio (BCR) and marginal benefit cost ratio (MBCR), as described in detail in other papers, using the following equation:

$$\text{MBCR} = \frac{\text{Gross Return}_{(\text{Specific Management})} - \text{Gross Return}_{(\text{Control})}}{\text{Variable Cost}_{(\text{Specific Management})} - \text{Variable Cost}_{(\text{Control})}}$$

Ethical approval: The conducted research is not related to either human or animal use.

3 Results and Discussion

3.1 Yield and yield contributing characters

3.1.1 Plant height

The application of nutrients in soil with or without CRI influenced the plant height significantly ($p \leq 0.05$) during both years in both AEZs (Table 3). It was however statistically different only for 'FP' and 'CON' with or without CRI, as compared with other nutrient management practices. The tallest plants were noted in 'HYG+CRI' and 'HYG', which might be due to more nutrients, especially N, through addition of balanced fertilizers as well as CRI. Basak *et al.* (2008) also reported the tallest plants in soil test based ('STB') nutrient application, with CRI, in Mustard-Boro rice-T. aman rice pattern and by Awal *et al.* (2007) in T. aman rice under Wheat-Jute-T. aman rice pattern, due to more N added to the soil than in STB without CRI. The lowest plant height was measured in 'CON', with or without CRI, which was probably due to no nutrient addition. In the second year, the plants were relatively smaller than in first year, but the trend was similar in both years (Table 3).

3.1.2 Number productive tillers m²

The number of productive tillers (NPT) m² differed significantly ($p \leq 0.05$) due to the application of nutrients to the soil in the first year. The highest NPT m² (305)

Table 3: Influence of different nutrient management strategies on plant height and productive tillers of rainfed monsoon rice in two locations of Bangladesh

| Nutrient management | Plant height (cm) | | | | Productive tillers (m ²) | | | |
|---------------------|-------------------|-----------|------------------|----------|--------------------------------------|--------|------------------|--------|
| | Bogra (AEZ-25) | | Jashore (AEZ-11) | | Bogra (AEZ-25) | | Jashore (AEZ-11) | |
| | 2011* | 2012 | 2011 | 2012 | 2011 | 2012 | 2011 | 2012 |
| HYG | 114.3 ab | 113.5 ab | 110.7 ab | 101.1 ab | 245 ab | 276 ab | 260 ab | 273 ab |
| MYG | 107.7 bcd | 107.0 bcd | 93.4 de | 83.8 de | 192 bc | 231 bc | 216 bc | 228 bc |
| IPNS | 111.3 abc | 110.3 abc | 102 bcd | 92.4 bcd | 285 a | 325 a | 266 a | 278 a |
| STB | 110.3 abc | 109.3 abc | 98.8 cde | 89.2 cde | 291 a | 332 a | 272 a | 285 a |
| FP | 106.7 cde | 105.7 cde | 96.0 cde | 86.4 cde | 155 cd | 198 cd | 170 c | 182 c |
| CON | 100.3 e | 99.3 e | 89.8 e | 80.2 e | 96 d | 132 d | 121 d | 134 d |
| HYG+CRI | 115.3 a | 114.3 a | 115.6 a | 106.0 a | 249 ab | 279 ab | 262 ab | 275 ab |
| MYG+CRI | 110.0 abc | 109.0 abc | 94.8 cde | 85.2 cde | 203 bc | 242 bc | 218 bc | 230 bc |
| IPNS+CRI | 114.3 ab | 113.3 ab | 105.1 bc | 95.5 bc | 299 a | 335 a | 270 a | 283 a |
| STB+CRI | 113.7 ab | 112.7 ab | 104.9 bc | 95.3 bc | 305 a | 342 a | 275 a | 288 a |
| FP+CRI | 108.0 bcd | 106.7 bcd | 97.1 cde | 87.5 cde | 158 cd | 200 cd | 172 c | 184 c |
| CON+CRI | 101.7 de | 100.7 de | 90.7 e | 81.1 e | 97 d | 133 d | 122 d | 135 d |
| CV (%) | 4.43 | 4.45 | 4.16 | 4.60 | 13.09 | 10.67 | 8.59 | 8.12 |
| F-test | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

HYG'; High Yield Goal, 'MYG'; Moderate Yield Goal, 'IPNS'; Integrated Plant Nutrient System, 'STB'; Soil Test Based, 'FP'; Farmer's Practice, 'CON'; without fertilizers, 'CRI'; crop residue incorporation.

*In each column, means followed by same lower-case letters are not significantly different at $p \leq 0.05$ level of significance.

were noted under 'STB' with CRI, though it was not statistically different from 'STB' (291), 'IPNS+CRI' (299), 'IPNS' (285), 'HYG+CRI' (249) and 'HYG' (245). Other nutrient management treatments resulted in moderate or low NPT m² with or without CRI. In the second year, the trend was similar though the response was greater than that in the previous year (Table 3). 'HYG', 'IPNS' and 'STB', with or without CRI, resulted in a higher number of panicles than other nutrient management practices, with the highest number from 'STB'. Though higher levels of nutrients were applied in 'HYG', this treatment failed to show positive effects on the number of panicles. In all treatments, nutrient management with CRI had more NPT m² than the treatments without CRI. Possibly, the CRI increased the plant nutrient availability which helped to increase the NPT (Hossain et al. 2016). Similar to the results of the current study, Ali et al. (2003) and Basak et al. (2008) also reported that 'STB' with CRI management resulted in the highest NPT m² in T. aman rice in Mustard-Boro rice-T. aman and in Mustard-Boro rice-T. aman rice cropping patterns respectively. Presumably, STB with CRI increased the nutrients availability for growing plants that ultimately led to increase in the NPT m² in T. aman rice.

3.1.3 Grains panicle⁻¹

Number of grains panicle⁻¹ (NGP) in both AEZs differed significantly ($p \leq 0.05$) with the application of different nutrients in combination with or without CRI in both years (Table 4). NGP was highest ($p \leq 0.05$) for 'STB', 'IPNS' & 'HYG', with or without CRI, in both years and in both AEZs, though they were not significantly different between each other. Similarly, the lowest numbers of NGP were recorded from 'CON' and 'FP' without CRI in both years and in both AEZs. Although higher amounts of nutrients were applied in 'HYG', the 'STB', with or without CRI, resulted in the maximum NGP, due to proper nutrient management (Table 4). In contrast, the 'CON', with or without CRI, resulted in the minimum NGP, due to no addition of nutrients into the soil or through residues. The results of the present study also agree with an earlier study reported by Naser et al. (2001), Zaman et al. 2007a, b, Hossain et al. (2016) and Jahan et al. (2016), who reported an increasing trend of NGP in treatments with CRI due to increase in the nutrient availability for growing plants that ultimately led to increase in NGP in T. aman rice.

Table 4: Influence of different nutrient management strategies on sterile spikelets per panicle and grains per panicle of rainfed monsoon rice at two locations in Bangladesh

| Nutrient management | Grains per panicle | | | | Number of sterile spikelets per panicle | | | |
|---------------------|--------------------|----------|------------------|-----------|---|----------|------------------|----------|
| | Bogra (AEZ-25) | | Jashore (AEZ-11) | | Bogra (AEZ-25) | | Jashore (AEZ-11) | |
| | 2011* | 2012 | 2011 | 2012 | 2011 | 2012 | 2011 | 2012 |
| HYG | 77.88 ab | 79.91 ab | 96.43 ab | 101.01 ab | 38.75 c | 41.76 c | 28.30 d | 27.01 d |
| MYG | 69.82 bc | 71.85 bc | 76.44 bc | 81.02 bc | 44.29 bc | 47.30 bc | 36.30 bc | 35.03 bc |
| IPNS | 90.73 a | 92.76 a | 100.37 a | 105.04 a | 26.99 d | 30.03 d | 22.30 d | 21.04 d |
| STB | 90.91 a | 92.94 a | 101.40 a | 106.03 a | 26.18 d | 29.76 d | 21.30 d | 20.02 d |
| FP | 49.64 d | 51.67 d | 56.45 cd | 61.04 cd | 47.19 ab | 50.20 ab | 43.30 ab | 42.03 ab |
| CON | 29.54 e | 31.57 e | 37.45 d | 42.02 d | 53.41 a | 56.42 a | 45.30 a | 45.03 a |
| HYG+CRI | 78.04 ab | 80.07 ab | 96.48 ab | 101.03 ab | 38.87 c | 41.88 c | 29.30 cd | 28.04 cd |
| MYG+CRI | 69.98 bc | 72.01 bc | 76.47 bc | 81.05 bc | 44.35 bc | 47.37 bc | 35.94 bc | 34.65 bc |
| IPNS+CRI | 94.97 a | 97.02 a | 102.31 a | 107.06 a | 27.96 d | 30.97 d | 22.07 d | 20.79 d |
| STB+CRI | 95.10 a | 97.13 a | 104.42 a | 108.03 a | 26.75 d | 29.19 d | 21.09 d | 19.81 d |
| FP+CRI | 50.72 cd | 57.75 cd | 57.44 cd | 62.03 cd | 47.52 ab | 50.53 ab | 42.88 ab | 41.58 ab |
| CON+CRI | 29.64 e | 31.67 e | 37.49 d | 42.04 d | 52.78 a | 55.79 a | 46.30 a | 44.04 a |
| CV (%) | 11.71 | 11.37 | 10.89 | 11.19 | 7.41 | 6.88 | 9.50 | 9.89 |
| F-test | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

HYG'; High Yield Goal, 'MYG'; Moderate Yield Goal, 'IPNS'; Integrated Plant Nutrient System, 'STB'; Soil Test Based, 'FP'; Farmer's Practice, 'CON'; without fertilizers, 'CRI': crop residue incorporation

*In each column, means followed by same lower-case letters are not significantly different at $p \leq 0.05$ level of significance.

3.1.4 Sterile spikelets per panicle

The number of sterile spikelets panicle⁻¹ (SSP) differed significantly ($p \leq 0.05$) between treatments, with or without CRI, in first year, ranging from 19.8 to 55.8 across years and AEZs. SSP was higher in AEZ-11 than AEZ-25 in both years. Among the treatments, the maximum SSP were recorded for 'CON' followed by 'FP', each with or without CRI. In contrary, statistically similar ($p \leq 0.05$) but minimum numbers of SSP were found for 'STB', 'IPNS' & 'HYG' with or without CRI (Table 4). The highest numbers of SSP with 'CON' and 'FP', with or without CRI, might be due to imbalanced or low amounts of nutrients in the soil from applied fertilizers as well as crop residues. Imbalanced fertilization leads to soil mining and soil sickness and imbalanced availability of nutrients results in low- and poor-quality yield. It can also lead to mining of soil nutrient reserves which results in short supply (Mahajan and Gupta 2009). On the other hand, 'STB', 'IPNS' & 'HYG', with or without CRI, resulted in the minimum numbers of SSP, which might be due to the balanced nutrients that helped increase the nutrient-use efficiency of the soil. The results of this study are also supported by Lv *et al.* (2015), who noticed that when soil available nutrient is excessively

low or excessively high, adjusting this should be based on balanced fertilization to properly increase or reduce the fertilization rate. Similarly, Mahajan and Gupta (2009) also reported that application of balanced fertilization in optimum quantities and in the right proportion through appropriate methods results in sustenance of soil fertility, leading to build-up of soil health and improving crop productivity. Therefore, to obtain higher fertilizer-use efficiency and the higher productivity from monsoon rice, positive nutrient balance is very essential for sustainable crop production.

3.1.5 1000-grain weight (g)

In the present research, various nutrients management practices, with or without CRI, in both the years and both AEZs did not influence 1000 grain weight (TGW) significantly ($p \leq 0.05$), with little variation in TGW from 22.2 to 22.8 in AEZ-25 and 20.9 to 21.7 in AEZ-11 in first year and from 23.1 to 23.9 in AEZ-25 and 22.1 to 22.8 in AEZ-11 in second year (Table 5). In AEZ-25, TGW was higher in 'IPNS' with CRI, while in AEZ-11 it was higher in 'STB' (22.8 g). TGW did not differ significantly, as a result all plants had

Table 5: Influence of different nutrient management strategies on 1000-grain weight of rainfed monsoon rice at two locations in Bangladesh

| Nutrient management | 1000-grain weight (g) | | | | Grain yield (t ha ⁻¹) | | | |
|---------------------|-----------------------|-------|------------------|-------|-----------------------------------|---------|------------------|---------|
| | Bogra (AEZ-25) | | Jashore (AEZ-11) | | Bogra (AEZ-25) | | Jashore (AEZ-11) | |
| | 2011 | 2012 | 2011 | 2012 | 2011 | 2012 | 2011 | 2012 |
| HYG | 22.53 | 23.52 | 21.38 | 22.53 | 5.13 ab | 5.20 ab | 4.78 ab | 5.01 ab |
| MYG | 22.78 | 23.26 | 21.12 | 22.27 | 4.29 bc | 4.36 b | 3.88 bc | 4.11 bc |
| IPNS | 22.52 | 23.39 | 21.38 | 22.53 | 5.37 a | 5.44 a | 4.99 a | 5.21 a |
| STB | 22.50 | 23.34 | 21.18 | 22.80 | 5.48 a | 5.55 a | 5.10 a | 5.33 a |
| FP | 22.29 | 23.46 | 21.18 | 22.60 | 2.71 d | 2.78 c | 2.98 c | 3.16 c |
| CON | 22.16 | 23.12 | 20.92 | 22.07 | 1.48 e | 1.55 d | 1.35 d | 1.58 d |
| HYG+CRI | 22.27 | 23.59 | 21.45 | 22.60 | 5.17 ab | 5.24 ab | 4.82 ab | 5.05 ab |
| MYG+CRI | 22.63 | 23.72 | 21.32 | 22.47 | 4.30 bc | 4.39 b | 3.92 bc | 4.14 bc |
| IPNS+CRI | 22.52 | 23.92 | 21.28 | 22.43 | 5.40 a | 5.47 a | 5.02 a | 5.25 a |
| STB+CRI | 22.46 | 23.86 | 21.65 | 22.33 | 5.51 a | 5.58 a | 5.13 a | 5.36 a |
| FP+CRI | 22.39 | 23.86 | 21.45 | 22.33 | 2.74 d | 2.81 c | 3.00 c | 3.21 c |
| CON+CRI | 22.23 | 23.12 | 21.12 | 22.27 | 1.50 e | 1.57 d | 1.36 d | 1.59 d |
| CV (%) | 3.33 | 3.70 | 3.35 | 3.23 | 8.67 | 8.52 | 11.04 | 10.42 |
| F-test | NS | NS | NS | NS | 0.01 | 0.01 | 0.01 | 0.01 |

HYG'; High Yield Goal, 'MYG'; Moderate Yield Goal, 'IPNS'; Integrated Plant Nutrient System, 'STB'; Soil Test Based, 'FP'; Farmer's Practice, 'CON'; without fertilizers, 'CRI': crop residue incorporation.

favourable environmental condition that ultimately led to similar grain size in all treatments (Table 5). Basak et al. (2008) also got similar grain size in all nutrient management practices in a different AEZ. Similarly, Satapathy et al. (2015) also reported that nutrient management was not significant for TGW under wet and dry season rice production system in subtropical India.

3.1.6 Grain yield

In both years and both locations, grain yield (GY) was significantly higher for 'MYG' compared to 'FP' or 'CON', but yields were not significantly different between other treatments, with the presence or absence of CRI. Maximum GY was recorded under 'STB' with CRI, followed by 'IPNS', & 'HYG'. On the other hand, GY was minimum under 'CON', followed by 'FP', each with or without CRI. Irrespective of treatments, GY was slightly higher in the second year than in first year (Table 5).

Results of the two-year study (Table 5) revealed that 'HYG', 'IPNS' and 'STB' nutrient management practices, with or without CRI, resulted in the highest GY, but were not significantly different between two AEZs. Among all the practices, 'STB' resulted in the highest GY, which might be

due to the combined effect of the higher number of tillers m², panicles m² and grains panicle⁻¹. 'MYG' and 'FP', with or without CRI, resulted in average and low GY, respectively, which might be because of moderate and low number of tillers m², panicles m² and grains panicle⁻¹. The lowest GY was found in the control treatment. In all the treatments with CRI, GY was superior to those without CRI (Table 5), which was due to residue effect. With the addition of crop residues, soil microbial activities were enhanced due to the addition of extra organic matter into the soil (Kavimadan et al. 1987 and Ladha et al. 2016). These results agree with that of Akhteruzzaman et al. (2009). On an average, maximum GY (5.24 t ha⁻¹) was recorded from 'STB+CRI' followed by 'IPNS+CRI', 'STB' and 'IPNS'. It is noted that 'STB', 'IPNS' and incorporation of residues played a vital role in increasing GY as well as improving soil health. Timsina et al. (2006a) reported the highest GY with 'STB' in rice on a rice-wheat-mungbean system in three AEZs in Bangladesh. Similar findings were also reported by other researchers (Hossain et al. 2016; Das et al. 2018).

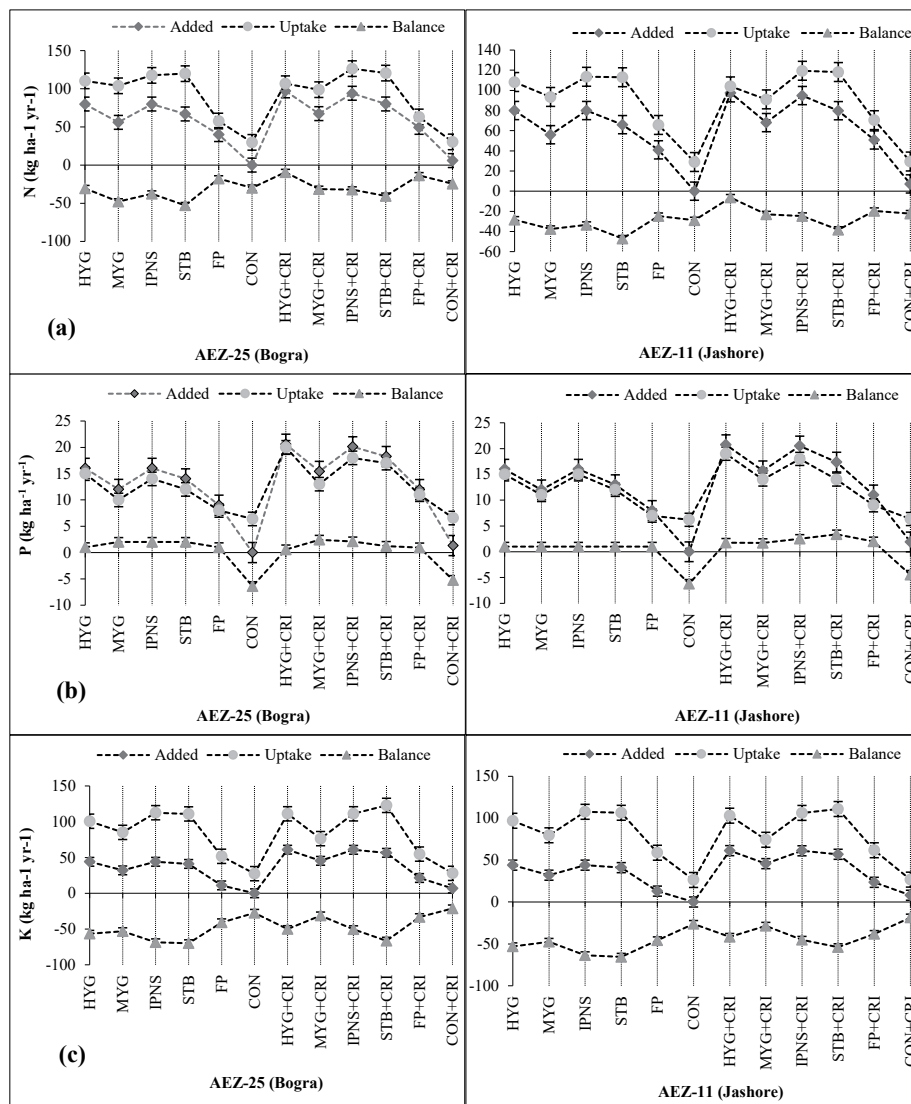


Figure 2: Nitrogen (a), phosphorus (b) and potassium (c) added, uptake and balance in rainfed monsoon rice fields in two locations (AEZ-25 & AEZ-11) of Bangladesh after two years of nutrient management. Mean (\pm SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test). HYG; High Yield Goal, 'MYG'; Moderate Yield Goal, 'IPNS'; Integrated Plant Nutrient System, 'STB'; Soil Test Based, 'FP'; Farmer's Practice, 'CON'; without fertilizers, 'CRI': crop residue incorporation; N, Nitrogen; P, phosphorus; K, potassium.

3.2 Apparent nutrient uptake and balance

Apparent nutrients (N, P, K, S, Zn and B) uptake by grain and straw of rice plants and their balances were influenced by application of different nutrients, with or without CRI, in both years and both AEZs (Figure 2 to 3).

3.2.1 Nitrogen

In both years, average maximum N uptake by grain and straw of rice was recorded in AEZ-25 than AEZ-11 (Table 6). Considering nutrient management, the highest N uptake

was noted in 'IPNS' with CRI, followed by STB, irrespective of CRI, while minimum uptake was observed under 'CON' (Table 6 and Figure 2). During N balance estimation, 50–60% N loss was considered in the water-filled pores of soil through mineralization (Jahan et al. 2014a,b; Jahan et al. 2016). Other researchers also indicated that 40% of N from applied chemical/cowdung/crop residues was considered effective (FRG 2012; Saidy 2013). The apparent N balance was found to be negative in all treatments ranging from -9 to -53 kg ha⁻¹ yr⁻¹. The maximum negative balance was found in 'STB' (-53 kg ha⁻¹ yr⁻¹) followed by 'STB+CRI' (-40 kg ha⁻¹ yr⁻¹), due to higher uptake of N as compared with the treatment with added N in soil through

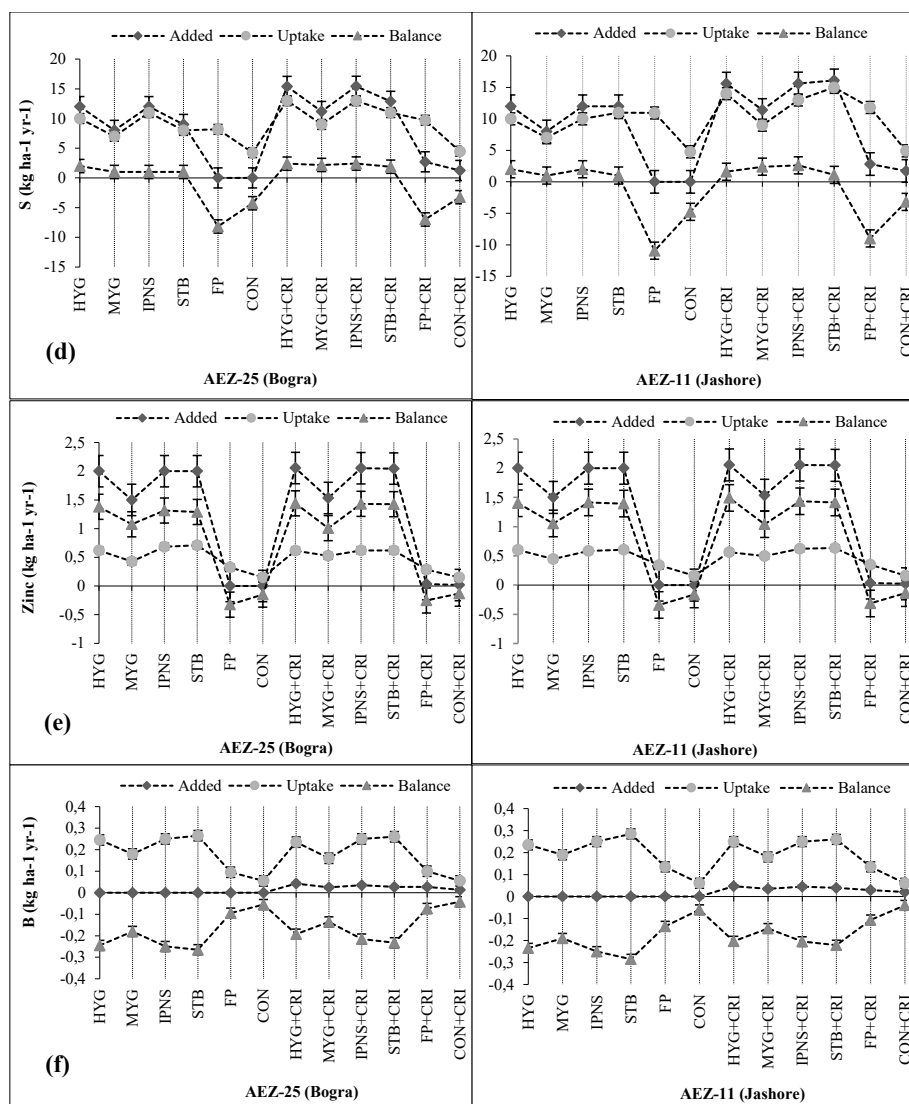


Figure 3: Sulphur (d) zinc (e) and (f) boron added, uptake and balance in rainfed monsoon rice field in two locations (AEZ-25 & AEZ-11) in Bangladesh after two years of nutrient management. Mean (\pm SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test). HYG; High Yield Goal, 'MYG'; Moderate Yield Goal, 'IPNS'; Integrated Plant Nutrient System, 'STB'; Soil Test Based, 'FP'; Farmer's Practice, 'CON'; without fertilizers, 'CRI'; crop residue incorporation; N, Nitrogen; P, phosphorus; K, potassium.

residues (7-18 kg ha⁻¹ across treatments). This was possibly due to addition of nutrients for two years, as well as due to CRI into the soil, which increased its available N status. N balance was negative in all treatments, indicating that the amount of N removed exceeded that added to the soil (Table 6 and Figure 2). Plant residues can decrease plant-available N through volatilization and immobilization (Dinkins et al. 2014).

In the present study, we noticed that N replenishment through chemical fertilizer, cowdung addition, CRI either

singly or in combination was not enough to replenish N removal by the crop; so much of the applied N was lost from the soil through depletion. The N balance thus was negative in all treatments, which appeared to remove in excess of the quantity added into the soil. However, the N balance was less negative in those treatments where crop residues were incorporated, which might be due to addition of extra N coming from the previous crop residues (Table 6 and Figure 2). The results of our study related to N uptake and balance are similar to the study by Timsina et al. (2006b), who also found N deficiency ranging from 33% to 95% in rice-wheat-mungbean or

able 6: Average nutrient uptake and balance (kg ha⁻¹) by grain and straw of rainfed monsoon rice in two locations of Bangladesh

| Treatments | AEZ-25 (Bogra) | | | | | | | | |
|------------|----------------|--------|---------|-------|--------|---------|-------|--------|---------|
| | N | | | P | | | K | | |
| | Added | Uptake | Balance | Added | Uptake | Balance | Added | Uptake | Balance |
| HYG | 80 | 110 | -30 | 16 | 15 | 1 | 44 | 101 | -57 |
| MYG | 56 | 104 | -48 | 12 | 10 | 2 | 32 | 85 | -53 |
| IPNS | 80 | 118 | -38 | 16 | 14 | 2 | 44 | 113 | -69 |
| STB | 67 | 120 | -53 | 14 | 12 | 2 | 41 | 111 | -70 |
| FP | 40 | 58 | -18 | 9 | 8 | 1 | 11 | 52 | -41 |
| CON | 0 | 30 | -30 | 0 | 6 | -6 | 0 | 27 | -27 |
| HYG+CRI | 97 | 107 | -9 | 21 | 20 | 1 | 61 | 111 | -50 |
| MYG+CRI | 67 | 99 | -31 | 15 | 13 | 2 | 45 | 76 | -31 |
| IPNS+CRI | 94 | 126 | -32 | 20 | 18 | 2 | 61 | 111 | -50 |
| STB+CRI | 80 | 121 | -40 | 18 | 17 | 1 | 57 | 123 | -66 |
| FP+CRI | 49 | 63 | -14 | 12 | 11 | 1 | 21 | 55 | -33 |
| CON+CRI | 6 | 30 | -24 | 1 | 7 | -5 | 7 | 28 | -21 |

| Treatments | S | | | Zn | | | B | | |
|------------|-------|--------|---------|-------|--------|---------|-------|--------|---------|
| | Added | Uptake | Balance | Added | Uptake | Balance | Added | Uptake | Balance |
| HYG | 12 | 10 | 2 | 2.00 | 0.62 | 1.38 | 0.00 | 0.25 | -0.25 |
| MYG | 8 | 7 | 1 | 1.50 | 0.43 | 1.08 | 0.00 | 0.18 | -0.18 |
| IPNS | 12 | 11 | 1 | 2.00 | 0.69 | 1.32 | 0.00 | 0.25 | -0.25 |
| STB | 9 | 8 | 1 | 2.00 | 0.71 | 1.29 | 0.00 | 0.27 | -0.27 |
| FP | 0 | 8 | -8 | 0.00 | 0.33 | -0.33 | 0.00 | 0.10 | -0.10 |
| CON | 0 | 4 | -4 | 0.00 | 0.15 | -0.15 | 0.00 | 0.06 | -0.06 |
| HYG+CRI | 15 | 13 | 2 | 2.06 | 0.62 | 1.44 | 0.04 | 0.24 | -0.19 |
| MYG+CRI | 11 | 9 | 2 | 1.53 | 0.53 | 1.01 | 0.02 | 0.16 | -0.14 |
| IPNS+CRI | 15 | 13 | 2 | 2.05 | 0.62 | 1.43 | 0.03 | 0.25 | -0.22 |
| STB+CRI | 13 | 11 | 2 | 2.05 | 0.62 | 1.43 | 0.03 | 0.26 | -0.23 |
| FP+CRI | 3 | 10 | -7 | 0.03 | 0.29 | -0.25 | 0.03 | 0.10 | -0.07 |
| CON+CRI | 1 | 4 | -3 | 0.02 | 0.15 | -0.13 | 0.01 | 0.06 | -0.04 |

| Treatments | AEZ-11 (Jashore) | | | | | | | | |
|------------|------------------|--------|---------|-------|--------|---------|-------|--------|---------|
| | N | | | P | | | K | | |
| | Added | Uptake | Balance | Added | Uptake | Balance | Added | Uptake | Balance |
| HYG | 80 | 108 | -28 | 16 | 15 | 1 | 44 | 97 | -53 |
| MYG | 56 | 93 | -37 | 12 | 11 | 1 | 32 | 80 | -48 |
| IPNS | 80 | 114 | -34 | 16 | 15 | 1 | 44 | 108 | -64 |
| STB | 66 | 113 | -47 | 13 | 12 | 1 | 41 | 107 | -66 |
| FP | 41 | 66 | -25 | 8 | 7 | 1 | 13 | 59 | -46 |
| CON | 0 | 29 | -29 | 0 | 6 | -6 | 0 | 26 | -26 |
| HYG+CRI | 98 | 104 | -6 | 21 | 19 | 2 | 61 | 103 | -42 |
| MYG+CRI | 68 | 91 | -23 | 16 | 14 | 2 | 46 | 74 | -28 |
| IPNS+CRI | 95 | 119 | -25 | 20 | 18 | 2 | 61 | 106 | -45 |
| STB+CRI | 80 | 118 | -38 | 17 | 14 | 3 | 57 | 111 | -54 |
| FP+CRI | 51 | 70 | -20 | 11 | 9 | 2 | 23 | 62 | -38 |
| CON+CRI | 7 | 29 | -22 | 2 | 6 | -4 | 8 | 27 | -19 |

| Treatments | S | | | Zn | | | B | | |
|------------|-------|--------|---------|-------|--------|---------|-------|--------|---------|
| | Added | Uptake | Balance | Added | Uptake | Balance | Added | Uptake | Balance |
| HYG | 12 | 10 | 2 | 2.00 | 0.60 | 1.40 | 0.00 | 0.24 | -0.24 |
| MYG | 8 | 7 | 1 | 1.50 | 0.45 | 1.06 | 0.00 | 0.19 | -0.19 |
| IPNS | 12 | 10 | 2 | 2.00 | 0.59 | 1.42 | 0.00 | 0.25 | -0.25 |
| STB | 12 | 11 | 1 | 2.00 | 0.61 | 1.40 | 0.00 | 0.29 | -0.29 |
| FP | 0 | 11 | -11 | 0.00 | 0.34 | -0.34 | 0.00 | 0.14 | -0.14 |
| CON | 0 | 5 | -5 | 0.00 | 0.16 | -0.16 | 0.00 | 0.06 | -0.06 |
| HYG+CRI | 16 | 14 | 2 | 2.06 | 0.57 | 1.49 | 0.05 | 0.25 | -0.20 |
| MYG+CRI | 11 | 9 | 2 | 1.54 | 0.50 | 1.04 | 0.03 | 0.18 | -0.15 |
| IPNS+CRI | 16 | 13 | 3 | 2.05 | 0.62 | 1.43 | 0.04 | 0.25 | -0.21 |
| STB+CRI | 16 | 15 | 1 | 2.05 | 0.64 | 1.41 | 0.04 | 0.26 | -0.22 |
| FP+CRI | 3 | 12 | -9 | 0.04 | 0.35 | -0.31 | 0.03 | 0.14 | -0.11 |
| CON+CRI | 2 | 5 | -3 | 0.02 | 0.16 | -0.14 | 0.02 | 0.06 | -0.04 |

HYG'; High Yield Goal, 'MYG'; Moderate Yield Goal, 'IPNS'; Integrated Plant Nutrient System, 'STB'; Soil Test Based, 'FP'; Farmer's Practice, 'CON'; without fertilizers, 'CRI': crop residue incorporation.

rice-maize-mungbean system in each year in three AEZs of Bangladesh, but deficiency in rice and mungbean was minimal, due to the addition of crop residues. Hossain et al. (2016) found higher N in the soil of a rice–wheat system in AEZ–25, when mungbean and rice residues were incorporated into the soil.

3.2.2 Phosphorus

Across treatments, years and AEZs, added P ranged from 0 to 21 kg P ha⁻¹ yr⁻¹ (Table 6 and Figure 2), with highest uptake under 'HYG' and 'IPNS' with CRI followed by STB+CRI, and lowest uptake under 'CON', followed by 'FP', with or without CRI. However, except 'CON', with or without CRI, all nutrients management treatments showed positive balances in both locations and years. The highest P balance was found under 'STB' with CRI, while, except 'CON' with or without CRI, other nutrients management treatments did not have significantly different in P balance though all were positive.

In the present study, though there was addition of higher amounts of P, its uptake was lower, which might be due to the total dry matter content as well as the variation in P concentration in the crop. In 'HYG', 'MYG', 'IPNS', 'STB' and 'FP', with or without CRI, the balance appeared positive with trace amounts due to the addition of adequate nutrients into the soil through the uptake was a little bit lower. However, the balance was a little bit higher in those treatments where the crop residue was incorporated into the soil than without incorporation, which might be due to addition of extra amounts of P in the range of 2-5 kg

ha⁻¹ yr⁻¹ through residues (Table 6 and Figure 2). Similar results were also found by Saleque et al. (2006). Swarup and Wanjari (2000) reported that when each component crop of an intensive production system receives P at a site-specific recommended rate, the apparent P balance remains positive in most growing situations. Except for 'CON' and 'FP', there was an increase in P with higher rates of crop residues. Several researchers also noticed that the addition of OM/crop residues played a beneficial role by retaining a portion of the added P in plant-available form by suppressing P sorption (Chauhan et al. 2012) and improving soil P fertility status (Damodar et al. 1999).

3.2.3 Potassium

Across AEZs and years, the quantity of added K to the soils ranged from 0 to 61 kg ha⁻¹ yr⁻¹, while uptake by rice varied from 26 to 123 kg ha⁻¹ yr⁻¹. K uptake was higher in AEZ-25 than AEZ-11, with highest uptake in 'STB' with CRI (123 kg ha⁻¹ yr⁻¹) followed by 'IPNS' with or without CRI (113 & 111 kg ha⁻¹ yr⁻¹ respectively) and lowest uptake in 'CON' (27 kg ha⁻¹ yr⁻¹) (Table 6 and Figure 2). All treatments showed negative balances (from -21 to -70 kg ha⁻¹ yr⁻¹), with the most negative being 'STB' and least negative being 'CON+CRI'. However, the magnitudes of negative balances were comparatively lower in treatments where crop residues were incorporated, presumably due to addition of extra nutrients (8 to 17 kg ha⁻¹ yr⁻¹) through residues incorporation (Table 6 and Figure 2).

In this study, the soil available K after two years was negative for all treatments, as compared to the initial

value (Figure 2) due to heavier removal of K by the rice crop than its application. In addition, the contribution from soil non-exchangeable to exchangeable K was also probably insufficient. These results clearly indicate that the K application to rice could not meet its K demand. This hypothesis is supported by Panaullah et al. (2006), who found large negative K balances for the rice-wheat-mungbean system at three sites in Bangladesh. In their study, many rice plants displayed K deficiency resulting in negative K balance. Similarly, Singh et al. (2014) also reported that the available K pool in the soil declined in all the nutrient management treatments, suggesting that K inputs from different sources were not sufficient to sustain soil K fertility under highly exhaustive wheat-rice sequences where crop residues, particularly rice straw, were removed from the fields.

3.2.4 Sulphur

Irrespective of treatments, the quantity of added nutrients across treatments, years and AEZs ranged from 0 to 15 kg ha⁻¹ yr⁻¹ while the uptake ranged from 4 to 13 kg ha⁻¹ yr⁻¹ (Table 6 and Figure 3). In both years, S uptake was higher in AEZ-11 than AEZ-25, with the highest uptake being under 'HYG' and 'IPNS' with CRI, followed by 'IPNS' and 'STB+CRI' and lowest uptake was under 'CON' and 'CON+CRI'. S balance was negative under 'FP' and 'CON' with or without CRI, while the remaining treatments showed positive balances, ranging from 1 to 2 kg ha⁻¹ yr⁻¹ (Figure 3). Except 'HYG' without CRI, all other treatments had no significantly different S balance (2 kg ha⁻¹ yr⁻¹). In 'HYG', 'MYG', 'IPNS', 'STB', with or without CRI, the balances appeared positive with trace amounts due to addition of adequate nutrients into the soil (2-5 kg ha⁻¹) though the uptake was a little bit lower (Table 6 and Figure 3). Singh et al. (2005) also reported that crop residue management is a major determinant of long-term S fertilizer requirement.

Plants assimilate S as SO₄ almost entirely through mineralization. S deficiency has also been highlighted by Jahan et al. (2014a), Jahan et al. (2016) and Hossain et al. (2016) in the soils of intensively cultivated rice systems in Bangladesh, due to low use of organic manures, removal of crop residues, and leaching as a form of SO₄ through rains and standing irrigation water. Incorporating crop residues however could reduce the S losses by leaching (Khan et al. 2005) and also would significantly increase S availability in soil (Whitbread et al. 1999).

3.2.5 Zinc

Across years and AEZs, Zn applied across treatments was 0 to 2.06 kg ha⁻¹; while its uptake was 0.15 to 0.71 kg ha⁻¹ yr⁻¹ (Table 6 and Figure 3), with highest uptake in 'STB' followed by 'IPNS' and the lowest in 'CON' and 'CON+CRI'. In both years and both AEZs, Zn balance was negative in 'FP' (-0.33 kg ha⁻¹ yr⁻¹) and 'CON+CRI' (-0.13 kg ha⁻¹ yr⁻¹) but all other treatments showed positive balances ranging from 1.01 to 1.44 kg ha⁻¹ yr⁻¹, with the highest balance in 'HYG+CRI' and lowest in 'MYG+CRI' (Table 6 and Figure 3). Lower balances were due to trace amounts of Zn nutrient uptake by the crop.

Farmers' practice and control plots had negative Zn balance because no Zn nutrient was added into the soil and only a little through residues (0.02-0.06 kg ha⁻¹) whereas a considerable amount of Zn was removed by the crop. Bhuiyan (2004) and Basak et al. (2008) also reported similar results in wheat-T.Aus/Mungbean-T. aman rice and groundnut-T.Aus-T. aman rice cropping patterns, respectively. The assumption that the crop residue incorporation leads to an increase in S and Zn levels is also supported by the findings of Saha et al. (2007), who reported the highest S uptake in STB+CD+GM in which dhaincha (*Sesbania aculeata* Poir.) was incorporated as green manure.

3.2.6 Boron

In the present study, the range of added B was 0-0.4 kg ha⁻¹ yr⁻¹ while the uptake was 0.06-0.27 kg ha⁻¹ yr⁻¹, with the highest uptake in 'STB' and lowest in 'CON' and 'CON+CRI' (Table 6 and Figure 3). Across AEZs and years, treatments with or without CRI showed negative B balances, with the most negative in 'STB' and the least negative in 'CON+CRI' (Table 6 and Figure 3). The negative B balances were due to non-addition of B to the soil from external sources and B released through CRI (0.02-0.05 kg ha⁻¹) was not enough to offset its uptake. Bhuiyan (2004) also reported similar results in a Wheat-T. Aus/ Mungbean- T. aman rice cropping pattern in Bangladesh. B is essential for plant growth, as its function is related to cell wall strength and development, cell division, fruit and seed development, sugar transport, and hormone development, with some functions interrelated with those of N, P, K and Ca (Freeman 2013; Fahad et al. 2014).

3.3 Economics of rice cultivation

Results of this study showed that in both AEZs, 'STB' fertilizer management with CRI resulted in the highest gross return (738 & 698 US\$ha⁻¹), followed by 'STB' (734 & 694 US\$ha⁻¹), 'IPNS+CRI' (724 & 683 US\$ha⁻¹), and 'IPNS' (720 & 679 US\$ha⁻¹), due to higher yields in those treatments (Table 7). With some exceptions, similar trends were also found for gross margin and net returns. In both AEZs, due to higher yields, BCR was also higher in STB management (3.54 & 3.36), followed by 'STB+CRI' (3.35 & 3.18) and 'IPNS' (3.26 & 3.09). Similarly, MBCR was also highest for 'STB' (10.47 & 10.19) followed by 'STB+CRI' (8.43 & 8.08), due to comparatively lower variable costs. Control plots, on the other hand, resulted in the lowest gross returns, gross margin, net returns and BCR due to low yield (Table 7). These results indicate that the overall economic performance of the aforesaid T. aman rice is sustainable with 'STB', 'STB+CRI' and 'IPNS' management. Other researchers (Jahan et al. 2016 and Hossain et al.

2016) also reported similar results for different cropping patterns and without CRI.

4 Conclusions and recommendation

Nutrient management practices (soil test-based management-STB, integrated plant nutrient systems-IPNS, and nutrient management for high yield goal-HYG), with or without integration of crop residues (CRI), can increase rice yield as well as improve the soil fertility. Further, 'STB' with CRI can result in greatest rice yield followed by 'IPNS' & 'HYG' with or without CRI. Results also demonstrate that residues can add extra nutrients into the soil. Residue incorporation or retention would be a good practice for maintaining long-term soil fertility and productivity in the sub-tropical climate of Bangladesh and South Asia where soil organic matter is generally low due to its higher decomposition resulting from the high activity of micro-organisms. Finally, it may be recommended that

Table 7: Economics of different nutrient management strategies in rainfed monsoon rice in two locations (AEZ-25 & AEZ-11) of Bangladesh (mean of 2011 and 2012)

| Treatments | Fixed cost (US\$ ha ⁻¹) | | Variable cost (US\$ ha ⁻¹) | | Total cost (US\$ ha ⁻¹) | | Gross return (US\$ ha ⁻¹) | | Gross margin (US\$ ha ⁻¹) | | Net return (US\$ ha ⁻¹) | | BCR | | MBCR (over control) | |
|------------|--|--------|---|--------|--|--------|--|--------|--|--------|--|--------|---------|--------|------------------------|--------|
| | 1 | | 2 | | 3=(1+2) | | 4 | | 5=(4-2) | | 6=(4-3) | | 7=(4/3) | | 8 | |
| | AEZ-25 | AEZ-11 | AEZ-25 | AEZ-11 | AEZ-25 | AEZ-11 | AEZ-25 | AEZ-11 | AEZ-25 | AEZ-11 | AEZ-25 | AEZ-11 | AEZ-25 | AEZ-11 | AEZ-25 | AEZ-11 |
| HYG | 157 | 157 | 57 | 56 | 214 | 214 | 687 | 651 | 630 | 595 | 474 | 437 | 3.22 | 3.05 | 8.52 | 8.1 |
| MYG | 157 | 157 | 41 | 41 | 198 | 198 | 576 | 531 | 534 | 490 | 377 | 333 | 2.91 | 2.68 | 9.04 | 8.24 |
| IPNS | 157 | 157 | 64 | 62 | 221 | 220 | 720 | 679 | 655 | 616 | 499 | 459 | 3.26 | 3.09 | 8.07 | 7.75 |
| STB | 157 | 157 | 51 | 49 | 208 | 207 | 734 | 694 | 683 | 644 | 526 | 487 | 3.54 | 3.36 | 10.47 | 10.19 |
| FP | 157 | 157 | 27 | 21 | 184 | 178 | 365 | 408 | 339 | 387 | 182 | 230 | 1.99 | 2.29 | 6.09 | 6.19 |
| CON | 157 | 157 | 0 | 0 | 157 | 157 | 202 | 195 | 202 | 195 | 45 | 37 | 1.29 | 1.24 | 0 | 0 |
| HYG+CRI | 157 | 157 | 70 | 69 | 227 | 226 | 693 | 656 | 623 | 587 | 466 | 430 | 3.06 | 2.9 | 7.03 | 6.7 |
| MYG+CRI | 157 | 157 | 53 | 52 | 210 | 210 | 578 | 536 | 526 | 484 | 369 | 326 | 2.76 | 2.56 | 7.13 | 6.54 |
| IPNS+CRI | 157 | 157 | 77 | 75 | 234 | 233 | 724 | 683 | 646 | 608 | 490 | 451 | 3.09 | 2.94 | 6.74 | 6.5 |
| STB+CRI | 157 | 157 | 64 | 62 | 220 | 220 | 738 | 698 | 674 | 635 | 517 | 478 | 3.35 | 3.18 | 8.43 | 8.08 |
| FP'+CRI | 157 | 157 | 37 | 30 | 193 | 188 | 369 | 413 | 333 | 383 | 176 | 225 | 1.92 | 2.2 | 4.59 | 7.2 |
| CON+CRI | 157 | 157 | 6 | 7 | 163 | 164 | 204 | 196 | 198 | 189 | 41 | 32 | 1.25 | 1.2 | 0.44 | 0.21 |

All US\$ values refer to US\$ amounts. Prices: rice grain, 0.13 US\$ kg⁻¹; rice straw, 0.003 US\$ kg⁻¹. Labour: Rainfed monsoon rice, 110-120 people (labour wage 1-1.5 US\$ person⁻¹ day⁻¹). Fertilizers and manure: urea (N), 0.08-0.09 US\$ kg⁻¹; triple super phosphate (P), 0.23-0.25 US\$ kg⁻¹; murate of potash (K), 0.19-0.20 US\$ kg⁻¹; gypsum (S), 0.06-0.8 US\$ kg⁻¹; zinc sulphate (Zn), 0.81-0.85 US\$ kg⁻¹; cow dung, 0.004-0.005 US\$ kg⁻¹.

BCR = Benefit-cost ratio; MBCR = Marginal benefit-cost ratio

HYG'; High Yield Goal, 'MYG'; Moderate Yield Goal, 'IPNS'; Integrated Plant Nutrient System, 'STB'; Soil Test Based, 'FP'; Farmer's Practice, 'CON'; without fertilizers, 'CRI': crop residue incorporation.

nutrient management strategies such as ‘STB’ or ‘IPNS’ with CRI could be economically viable for monsoon rice cultivation in Bangladesh and similar soils and areas in South Asia.

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