Rice straw as a source of potassium for wetland rice cultivation

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ABSTRACT
Rice crops uptake large amounts of potassium (K), which is mainly supplied from inorganic fertilizer. Alternate K sources are essential to preserve natural reserves and to recycle unused K containing stubbles. We have evaluated the performance of rice straw (RS) in farmers’ field following integrated plant nutrient system (IPNS) for supplementing K requirement of rice and compared with agro-ecological zone (AEZ)-based chemical fertilizer and farmers’ practice in Tista Meander Floodplain soils of Bangladesh during 2013–2015. Application of RS @ 4.5 t ha−1 + IPNS-based fertilizer replaced full dose of chemical K fertilizer without significant reduction in grain yield of Boro rice. The K uptake with RS incorporation was similar to AEZ-based chemical fertilizer use. Considering soil health and environmental issue, RS + IPNS-based fertilizer management was the best option for growing wetland rice.

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1. Introduction
Adequate rice (Oryza sativa L.) production is the key to ensure food security in Bangladesh (Kabir et al., 2015) because rice security is synonymous to food security in this country. Production of rice requires nitrogen (N), phosphorus (P), and potassium (K) as major nutrient elements. These elements are important both in terms of the extent of their deficiencies in the soils, and their potential for crop yield increase or decrease (Kamrunnahar, Ahmad, Iqbal, Akter, & Islam, 2017). Since N, P, and K nutrient removals are increasing gradually (Islam & Muttaleb, 2016), farmers are generally utilizing chemical fertilizers to meet greater nutrient requirement for crop production. Chemical K fertilizer is produced from underground K salt deposits, which requires complex and expensive technique. No K deposits are available in Bangladesh to produce muriate of potash (MoP) fertilizer, although its demand is increasing for more crop production. In Bangladesh, the demands of MoP has increased in an exponential growth rate (6.15 per annum) during 1981–2010 and its projected demand will be 361.32 thousand metric tons in 2020 (Nahe et al., 2015) requiring huge amounts of foreign exchange to import. Thus, an alternative K source can save foreign currencies and reduce rice production cost.

Extensive use of inorganic fertilizers not only degrade soil physicochemical properties along with soil organic matter (OM) depletion (Ali, Islam, & Jahiruddin, 2009; Singh, Verma, Ansari, & Shukla, 2014), but also unable to sustain desired yield goal. A good supply of OM is essential for sustaining soil fertility and crop productivity, although organic manures alone cannot ensure sustainable rice production. Therefore, use of organic and inorganic sources in an integrated approach is the best management practices for sustaining soil health and crop productivity (Sarkar, Rahman, Rahman, Naher, & Ahmed, 2016) under varied agro-ecological zones (AEZ) of Bangladesh.

Rice plants uptake K in larger amounts compared to N and P (Islam, Chandrabiswas, Karim, Salmapervin, & Saleque, 2015; Islam, Saha, Biswas, & Saleque, 2016). In general, about 103 kg K is removed for 7.0 t ha −1 grain harvest (Bangladesh Agricultural Research Council [BARC], 2012); but K requirement varies with rice varieties and yield goal (Islam & Muttaleb, 2016). This luxurious K uptake depletes soil K reserve because of limited applications by the farmers from chemical fertilizer (Biswas, Islam, Biswas, & Islam, 2004). Moreover, intensive cropping with modern high yielding varieties are enhancing soil K depletion in light textured soils of Bangladesh (Saha, Miah, Hossain, Rahman, & Saleque, 2009) resulting in a negative K balance of 100–225 kg−1 ha−1 yr−1 (Rijmpa & Islam, 2002; Zhang et al., 2010). Tista Meander Flood Plain soils of Bangladesh are light textured and acidic, but farmers are growing more than two crops in a year with or without adequate fertilizer application ad in most cases no organic materials are applied. Since OM content is decreasing in most soils of Bangladesh (Ali, Shahid, Kubota, Masunaga, & Wakatsuki, 1997), looking for...
alternate avenues of enriching soil carbon is very much essential for sustaining crop production.

Rice straw production is plenty in Bangladesh, but its removal from the field resulting in loss of K and Si reserves (Dobermann & Fairhurst, 2002). This resource can be recycled because it is a rich source of K (1.6%), N (0.5%), P (0.08%), S (0.09%), and 0.01% Zn (Saha, Hossain, Naher, & Saleque, 2004) along with 0.40% calcium, 0.24% magnesium, and 6.30% silicon. Use of rice straw in paddy soil not only improved organic C, N, and available P, K, and Si (Ponnamperuma, 1984) but also showed more than one ton per hectare yield advantage of Boro rice (Saha et al., 2009). Not many studies on the use of RS under farmer’s field conditions are reported, although a plenty of literature is available in inorganic K management. Therefore, this study was carried out in farmers’ fields with IPNS approach to assess the suitability of RS as an alternative to inorganic K fertilizer application for wetland rice production under rice–rice cropping system.

2. Materials and methods

2.1. Site description

The experiment was conducted in the farmer’s fields having rice–rice cropping system during 2013–2015. The experimental sites were located in Rangpur region covering seven upazilas viz. Gongachora (25.8500°N 89.2167°E), Badarganj (25.40°N 89.03°E) and Taraganj (25.8111°N 89.0167°E) of Rangpur district, Nageshawry (25.9792°N 89.7083°E) and Kurigram Sadar (25.8167°N 89.6500°E) of Kurigram district, Lalmonirhat Sadar (25.9153°N 89.4500°E) of Lalmonirhat district and Nilphamari Sadar (25.9417°N 88.8444°E) of Nilphamari district (Figure 1). Experimental sites belong to Tista Meander Floodplain (AEZ 3). Non-calcareous Grey Floodplain soils and Non-calcareous Brown Floodplain soils are predominant and the climate is subtropical. Generally, three distinct seasons: a hot, humid summer from March to June; a cool rainy monsoon season from June to October; and a cool dry winter from October to March prevail in this region. Some basic soil chemical properties of the study locations are presented in Table 1.

2.2. Experimental design and treatments

Randomized complete block design with three treatments were followed and each field was considered as a block (replication). In a season, the experiment was carried out in six farmers’ field in three upazilas. Farmers’ fields were selected through group discussion with the farming communities to ensure fertilizer management practices of selected farmers are representative of the respective location. The treatments were: AEZ-based chemical fertilizer, rice straw (RS) @ 4.5 t ha⁻¹ + IPNS-based chemical fertilizer, and farmers’ practice (FP).
2.3. Transplanting and management

The test varieties were BRRI dhan29 and BRRI dhan58 in Boro season and BRRI dhan49 and BRRI dhan52 in T. Aman season. Two to three 30 days old seedlings in T. Aman and 40 days old in Boro seasons were transplanted at 20 cm × 20 cm spacing. In T. Aman season, transplanting was done in the second week of July and in Boro season; it was in the first week of January. Nitrogen, P, K, S, and Zn were applied as Urea, TSP, MoP, Gypsum, and Zinc sulphate, respectively. Full dose of TSP, MoP, Gypsum, Zinc sulphate, and 1/3rd of urea were applied as basal. The remaining 2/3rd of urea was applied at maximum tillering stage and before one week of panicle initiation at equal split. All the intercultural operations and appropriate plant protection measures were taken when necessary.

2.4. Soil analysis

Initial soil samples were collected from each field and processed for chemical analysis. Soil samples were analyzed for pH, total organic carbon, total N, exchangeable K, and available S following the standard procedure described by Jackson (1973), Black (1965), Olsen, Calc, Watanabe, and Dean (1954) and Page, Miller, and Keeney (1982).

2.5. Plant sample analysis

Plant samples were collected at harvesting for N, P, and K analysis and nutrient uptake by rice plants. Total N was determined by Micro Kjeldhal method (Bremner, 1965) and P, K, and S contents were determined by nitric-perchloric acid digestion method (Yamakawa, 1992). The nutrient uptake was calculated as:

\[
\text{Nutrient uptake (kg ha}^{-1} \text{)} = \text{Nutrient content (%) \times Yield (t ha}^{-1} \text{)} \times 10
\]

2.6. Harvesting

Crops were harvested manually at maturity. Grain yield was calculated from 5 m² area and adjusted to 14% moisture content. Straw yield was calculated on oven dry basis from randomly collected 16 hills from the ground level (Sarkar et al., 2016).

2.7. Statistical analysis

The box plot is a standardized way of displaying the distribution of data based on the five number summaries: minimum, first quartile, median, third quartile, and maximum. The yield data of grain and straw were presented in box plots. The data of nutrient concentration and uptake were analyzed statistically by applying analysis of variance. The mean comparisons were made by least significant difference (LSD) test at 5% level of significance, where significance was indicated by F-test (Gomez & Gomez, 1984). Statistical Tool for Agricultural Research (STAR 2.0.1, International Rice Research Institute, Philippines) was used for computation.

3. Results and discussion

3.1. Grain and straw yields

Considering median values, grain yield in Boro season was 7.93 t ha⁻¹ with RS + IPNS and 7.87 t ha⁻¹ with AEZ-based fertilizer management, which were greater than FP (Figure 2(a)). Slightly higher grain yield in RS + IPNS

### Table 1. Some major soil chemical properties of the study locations.

| Locations      | pH     | Total organic carbon (%) | Total N (%) | K (meq per 100 g soil) | Available P (mg kg⁻¹) | Available S (mg kg⁻¹) |
|----------------|--------|--------------------------|-------------|------------------------|-----------------------|-----------------------|
| Badarganj      | 6.0–6.3| 1.10–1.30                | 0.10–0.13   | 0.12–0.15              | 15.47–18.0            | 20.50–26.12           |
| Taraganj       | 5.8–6.0| 1.21–1.37                | 0.12–0.14   | 0.12–0.17              | 12.02–14.31           | 17.31–22.22           |
| Gongachora     | 6.0–6.2| 1.20–1.44                | 0.11–0.13   | 0.11–0.18              | 13.23–16.68           | 16.40–23.00           |
| Nageshwary     | 5.5–5.8| 0.90–1.10                | 0.10–0.12   | 0.10–0.13              | 8.56–12.05            | 12.54–17.80           |
| Kurigram sadar | 5.5–6.0| 0.91–1.11                | 0.09–0.11   | 0.10–0.15              | 10.15–13.33           | 15.11–17.53           |
| Lalmorihit sadar | 5.7–6.2| 0.88–0.95                | 0.09–0.11   | 0.11–0.15              | 9.25–12.10            | 16.43–19.23           |
| Nilphamari sadar | 5.6–6.0| 0.92–1.20                | 0.09–0.11   | 0.12–0.14              | 10.51–12.50           | 20.10–22.21           |

*Rice straw @ 4.5 t ha⁻¹ was applied.

### Table 2. Nutrients rates for different treatments and seasons.

| Treatments                        | Nutrient rate (kg/ha) |
|-----------------------------------|-----------------------|
|                                   | T. Aman | Boro |
| AEZ-based fertilizer dose         | 70      | 10   | 33   | 10   | 3.0 | 170 | 20 | 59 | 15 | 4.0 |
| RS + IPNS                        | 47      | 6    | –    | 6    | 2.8 | 147 | 15 | –  | 11 | 3.8 |
| FP                               | 60      | 15   | 20   | –    | –   | 114 | 16 | 60 | 13 | –   |

The unit plot size was 8 m × 6 m. Nutrient rate for the respective treatments is presented in Table 2.
3.2. Nutrient concentration in grain and straw

Nitrogen, P and K concentrations in rice grain and straw were analyzed in T. Aman 2014 and Boro 2015 seasons. The N, P, and K concentrations significantly varied with different fertilizer management practices (Tables 3 and 4). In T. Aman 2014, the highest N concentration in grain was found in AEZ-based chemical fertilizer, which was statistically similar to RS + IPNS-based chemical fertilizer. Different fertilizer management did not influence the straw N concentration. Application of AEZ-based chemical fertilizer dose and RS + IPNS-based chemical fertilizer resulted in similar P concentration in rice grain and straw. Farmers’ practice always had significantly lower NPK in grain and PK in straw. Straw K concentrations were higher in AEZ-based chemical fertilizer compared to RS + IPNS-based chemical fertilizer (Table 3).

In Boro 2015 season, AEZ-based chemical fertilizer and RS + IPNS-based chemical fertilizer showed statistically identical effect on P and K concentrations in rice grain and straw. Nitrogen concentration in rice grain was significantly higher in AEZ-based chemical fertilizer than RS + IPNS-based chemical fertilizer. However, N concentration in rice straw was similar for these two treatments (Table 4). Our findings correspond to Saha et al., (2009).

3.3. Nutrient uptake

In T. Aman 2014 and Boro 2015 seasons, total NPK uptake by rice plant was significantly higher in AEZ-based and RS + IPNS-based fertilizer management compared to AEZ-based and RS + IPNS-based fertilizer management.
Conclusion

The combined application of rice straw and chemical fertilizer resulted in similar rice grain yield with AEZ-based chemical fertilizer application in Boro season. Use of rice straw showed similar K uptake with chemical K source both in T. Aman and Boro seasons. Since organic matter depletion is a major problem in Bangladesh, rice straw can be effectively utilized following IPNS technique.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Table 3. Treatment effects on the nutrient (NPK) concentration in rice grain and straw in T. Aman 2014

| Treatment               | Grain Concentration (mg g⁻¹ dry weight) | Straw Concentration (mg g⁻¹ dry weight) |
|-------------------------|----------------------------------------|----------------------------------------|
| AEZ-based fertilizer dose | 11.66 ± 0.32 a | 2.83 ± 0.10 a |
| RS + IPNS               | 12.01 ± 0.22 a | 2.80 ± 0.07 a |
| FP                      | 9.36 ± 0.31 b | 2.61 ± 0.09 b |
| Significance level      | ***          | *            |
| CV (%)                  | 4.59         | 3.3          |

Table 4. Treatment effects on the nutrient (NPK) concentration in rice grain and straw in Boro 2015

| Treatment               | Grain Concentration (mg g⁻¹ dry weight) | Straw Concentration (mg g⁻¹ dry weight) |
|-------------------------|----------------------------------------|----------------------------------------|
| AEZ-based fertilizer dose | 10.85 ± 0.16 a | 2.00 ± 0.09 a |
| RS + IPNS               | 10.44 ± 0.17 b | 1.96 ± 0.06 a |
| FP                      | 8.87 ± 0.07 c | 1.67 ± 0.08 b |
| Significance level      | ***          | **           |
| CV (%)                  | 7.10         | 10.17        |

Table 5. Effect of different fertilizer managements on the total (grain + straw) nutrient (NPK) uptake by rice in T. Aman 2014 and Boro 2015

| Treatment               | Total Nutrient Uptake (kg ha⁻¹) |
|-------------------------|---------------------------------|
|                         | 2014                            | 2014–15                          |
| AEZ-based fertilizer dose | 91.86 ± 5.82 a | 121.96 ± 2.72 a |
| RS + IPNS               | 82.25 ± 2.63 b | 119.98 ± 3.65 a |
| FP                      | 64.15 ± 4.26 c | 102.21 ± 7.62 b |
| Significance level      | ***          | **           |
| CV (%)                  | 8.78         | 7.16         |
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