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Growth, yield and nitrogen use efficiency of dry-seeded rice as influenced by nitrogen and seed rates in Bangladesh

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ABSTRACT

The fertilizer N requirement of dry-seeded rice (DSR) grown with alternate wetting and drying (AWD) water management may differ from that of traditional puddled transplanted rice (PTR) grown under continuous flooding due to differences in N dynamics in the soil/water system and crop growth patterns. The effects of changing establishment method and water management on N fertilizer requirement may also vary between crops grown in the dry and rainy seasons. Therefore, field experiments were conducted over two years in both the boro (dry) and aman (wet) seasons in Bangladesh to evaluate the effects of N rate and seed rate on crop performance and N use efficiency. Four N rates were used in the boro (0, 100, 140, and 180 kg ha^{-1}) and aman (0, 80, 120, and 160 kg ha^{-1}) seasons, and five seed rates (20, 40, 60, 80, and 100 kg ha^{-1}) were used in both seasons. There was a significant interaction between N rate and seed rate on grain yield of all crops. Maximum yield of all crops was achieved at the highest N rate with a seed rate of at least 40–60 kg ha^{-1}, suggesting that DSR has a higher fertilizer N requirement than the recommended rate for PTR. However, there was lodging at physiological maturity of the aman crops at 20 and 40 kg seed ha^{-1} at the maximum N rate, but not at 60 kg ha^{-1}, suggesting that at seed rates of 20–40 kg ha^{-1} a lower N rate than the maximum tested would be optimal. Agronomic fertilizer N use efficiency (15–20 kg grain kg^{-1}) and N recovery efficiency (35–40%) were low and comparable to the values reported in Asia for PTR, indicating the need for methods to improve fertilizer use efficiency of DSR. The boro crops sown in mid November suffered from cold damage, resulting in some seedling death in the first year, and substantial seedling death in the second year. In the second year, all boro sowings from mid November to mid January failed due to low temperature. The results suggest that dry seeding of boro rice in mid November is risky because of low temperature in December–January. However, delaying sowing to early February reduced yield due to high temperature during anthesis and low solar radiation during grain filling. Therefore, boro varieties with greater cold tolerance during the vegetative stage are needed to enable the switch from PTR to November-sown dry-seeded boro rice in the High Ganges River Floodplain of western Bangladesh.

1. Introduction

Boro (dry season rice) and aman (rainy season rice) provide 55% and 38%, respectively, of the rice grain produced in Bangladesh (BBS, 2014). Both crops are normally established by transplanting into puddled soil, and grown with prolonged or continuous flooding. Boro production is fully irrigated, and supplementary irrigation of aman is sometimes needed to establish the crop on time, or during dry spells. However, the sustainability of puddled transplanted rice (PTR) is threatened by increasing costs of production (especially labor and diesel) and increasing labor scarcity which delays crop establishment beyond the optimum time (Chauhan et al., 2012). Furthermore, groundwater levels are declining in major boro producing areas (Shamsudduha et al., 2009). Replacement of puddling and transplanting with dry-seeded rice (DSR) into non-puddled soil has the potential to facilitate timely estab-

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lishment and reduce establishment costs through reduced energy and labor for tillage and reduced labor for transplanting. Dry seeding also requires less water for crop establishment than puddling (Cabangon et al., 2002; Sudhir-Yadav et al., 2014). Furthermore, use of alternate wetting and drying (AWD) water management greatly reduces irrigation input to rice, and reduces it by more in DSR than PTR (Sudhir-Yadav et al., 2011b).

Nitrogen (N) is the most limiting nutrient for rice production and is required more consistently and in larger amounts than other nutrients (Cassman et al., 2002; Mahajan et al., 2011). Nitrogen transformations and availability are greatly affected by soil and water management. Flooded puddled soil tends to be anaerobic and ammonium is the dominant form of available N (Peng et al., 2010; Vlek and Craswell, 1981), whereas the soil at the time of dry seeding is aerobic and nitrate is usually the dominant form of available N. N losses from puddled, flooded soils are often large, with losses of up to 60% reported via ammonia volatilization from the floodwater (De Datta, 1986; Xing and Zhu, 2000). Denitrification losses from flooded puddled soils are also often large, ranging from negligible to 46% of the applied fertilizer N depending on N fertilizer application and crop establishment methods (Buresh and De Datta, 1990). Oxidized zones develop near the soil water interface and in the rhizosphere, and some of the ammonium is nitrified in these zones. From here nitrate diffuses into reduced zones, where it is ultimately denitrified to N_2 and/or N_2O and lost to the atmosphere (De Datta, 1981). On the other hand, in non-flooded, dry-seeded systems, the dominant form of N is usually nitrate, and therefore at risk of N loss by leaching following irrigation or rain, or by denitrification in low permeability soils which remain waterlogged after rain or irrigation (Humphreys et al., 1987a,b), and which have sufficient available carbon substrate. If urea is applied prior to irrigation of non-flooded soils, ammonia volatilization losses are likely to be low as the urea is transported below the soil surface (Humphreys et al., 1988; Prasad, 2011); however, on highly permeable soils, leaching beyond the root zone can be substantial (Katyal et al., 1984, 1988).

Seed rates in DSR are often much higher than in transplanted rice (Kumar and Ladha, 2011), resulting in higher tillering and early biomass production, and higher tiller mortality at later stages (Chauhan et al., 2011; Sudhir-Yadav et al., 2011a). These differences become more pronounced as seed rate in DSR increases (Ahmed et al., 2014a). The differences in crop growth patterns and soil N transformations and transport between flooded PTR and non-flooded DSR may result in different fertilizer-N requirements and efficiencies (Cassman et al., 1998; Sreekala et al., 2010; Mahajan et al., 2011, 2012).

There are few reports of comparisons of N management and requirement for DSR and PTR in general, little information on the interaction between N rate and seed rate for DSR in South Asia, and none for Bangladesh. In Punjab, India, yield of PTR increased with N rate up to 120 kg N ha^{-1}; however, DSR yield increased at rates up to 150 kg N ha^{-1} (Mahajan and Timsina, 2011). In Bangladesh, the general N recommendation for PTR is 140 and 120 kg ha^{-1} in the boro and aman seasons, respectively. However, there are no evidence-based N recommendations for DSR in either season.

Therefore, experiments were conducted to study the interaction between N fertilizer rate and seed rate of dry-seeded aman and boro (grown with AWD water management) in the High Ganges River Floodplain of Bangladesh, and to use this information to determine the optimum N rate × seed rate combinations for maximum yield of each crop. The hypotheses were that: (i) dry-seeded aman and boro crops require larger amounts of N fertilizer for maximum yield than the recommended rate for PTR, and (ii) that there are trade-offs between seed rate and N fertilizer rate for maximum yield of DSR. The objectives were to evaluate the effects of N rate and seed rate and their interactions on the growth, yield, and nitrogen use efficiency of DSR.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at the research farm of the Regional Agricultural Research Station (RARS) of the Bangladesh Agricultural Research Institute (BARI), Jessore (23°11′ N, 89°14′ E, 16 m ASL) during the boro (dry) seasons of 2011–12 (November to May) and 2012–13, and the aman (rainy) seasons of 2012 and 2013 (June–October). Boro and aman crops were grown in rotation on the same site in a boro-aman rotation. The experimental site was located on the High Ganges River Floodplain, a region of relatively high land not subject to flooding. The climate of the area is subtropical, with average annual rainfall of 1590 mm, 90% of which falls from June to October. Temperature during the aman season is favorable for rice production, with mean monthly minimum and maximum temperatures of around 25 and 35 °C, respectively. Temperature during the first part of the boro season is much lower, with mean minimum and maximum values of 10 and 25 °C, respectively, in January, increasing steadily to means of 25 and 36 °C in April/May. The topsoil (0–15 cm) of the experimental site is a clay loam with a bulk density of 1.60 Mg m^{-3}, pH of 7.6 (1:2 soil:water), organic carbon 1% (wet oxidation method), sand 30%, silt 33%, and clay 37%. The site had been under a wheat-mungbean-fallow cropping system for many years prior to establishment of the experiment. All wheat and mungbean grain and crop residues were removed at the time of harvest of each crop.

2.2. Experimental design

Four N rates (0, 100, 140, and 180 kg ha^{-1} for boro, or 0, 80, 120 and 160 kg ha^{-1} for aman, main plots) and five seed rates (20, 40, 60, 80, and 100 kg ha^{-1}, subplots) were compared in a split-plot design with three replicates. The size of each subplot was 4.5 m × 3 m. Main plots were separated by a 1 m buffe, and subplots by a 0.75 m buffer. The same treatments were applied to the same plot each season.

2.3. Crop management

Prior to the start of the first experiment (2011–12 boro), the field was cultivated and leveled using laser guidance. Before sowing each subsequent crop, the experimental area was dry cultivated using a rotavator then levelled using a steel leveller, both powered and drawn by a four-wheel tractor. Composed cow dung at 5 t ha^{-1} was applied prior to tillage for the first aman crop, because of the apparent very low fertility of the site as indicated by the poor growth and yield of the preceding boro crop. Dry seeds of rice cultivar BRRI dhan28 (140-d duration) for boro and BRRI dhan49 (135-d) for aman were sown by hand into shallow furrows made using a hand-drawn single tyne furrower, at a row spacing of 20 cm. The aman crops were sown on 20 June in both years (2012, 2013). The boro crops were sown on 15 November 2011 and 2012, however, unusually cold weather in December 2012 and January 2013 (Figs. 1 and 2) killed the second boro crop (15 November 2012 sowing). The cold weather also killed subsequent sowings in November and December 2012, while January 2013 sowings failed to emerge. Establishment on 1 February 2013 was successful; therefore, results are presented for this crop which is referred to as the 'boro 2012–13′ crop for simplicity.

The seeds of all boro and aman crops were planted at a depth of about 2 cm. The seed was weighed separately for each row in each plot for more uniform seed distribution. Furthermore, in the lowest seed rate treatment (20 kg ha^{-1}), the seeds were placed carefully in the furrows to ensure even spacing between the seeds, while at higher rates the seeds were carefully sprinkled along the furrows. Immediately before making the seeding furrows, all fer-