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Improved nursery management further enhances the productivity of stress-tolerant rice varieties in coastal rainfed lowlands

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ABSTRACT

The productivity of rice in most tropical coastal areas of Asia is low because of the predominance of several abiotic and biotic stresses, use of long duration traditional landraces or old varieties and suboptimal management practices. A combination of high-yielding, stress-tolerant rice varieties and good management practices is necessary to enhance the productivity of these areas. Suboptimal nursery management using traditional methods practiced in these areas often leads to a reduced plant population because of seedling mortality leading to poor yields. Nursery management practices that suit the new stress-tolerant varieties recently becoming available need to be developed to increase the productivity of rice. On-station and on-farm trials on nursery management were conducted using improved rice varieties to study the effect of seed density, nutrient management in the nursery, and seedling age at transplanting on grain yield. Lower seed density and application of balanced nutrients produced healthy and taller seedlings with high seedling vigor index (SVI) in the nursery and with subsequent significant increase in grain yield after transplanting in the main field. Combining inorganic and organic fertilizers in the seedbed (50–30–15 kg N–P_2O_5–K_2O ha^{-1} + 5 t ha^{-1} farm yard manures; FYM) enhanced seedling growth (dry weight, shoot and root length, number of green leaves, leaf area) and leaf nitrogen concentration. Forty-d-old seedlings produced significantly higher yield than 25-d-old seedlings. Transplanting older seedlings is important in systems without good water control, un-leveled fields, and soils affected by salt stress; and taller seedlings help avoid losses caused by floods. The highest benefit/cost ratios of 1.82, 1.72 and 1.91 were observed when transplanting 40-d-old seedlings using a seed density of 25 g m^{-2} and with balanced nutrient application of 50–30–15 kg N–P_2O_5–K_2O + 5 t FYM ha^{-1}, respectively. In the on-farm trials, the yield advantages when using new stress-tolerant rice varieties Swarna-Sub1 and Amal-Mana with improved nursery management practices were 23% and 47%, in comparison with farmers' nursery management and farmers' variety, respectively. These cost-effective nursery management approaches have great potential for enhancing yield in stress-prone rainfed coastal areas and will help sustain rice yield while ensuring sustainability of the cropping system.

1. Introduction

Coastal tropical deltas constitute a major rice production environment in south and southeast Asia. However, they are often subject to flash floods or prolonged waterlogging caused by heavy monsoon rains in the wet season and the infrequent weather calamities such as coastal storms and cyclones, causing serious floods and salt intrusion (Ismail and Tuong, 2009). Soils in these areas are saline during the dry season and at the beginning of the wet season. Combined with poor surface and subsurface drainage, these conditions limit the choices of crops and the use of improved varieties.

One example of such system is the *Sundarbans* area of the lower Gangetic delta, located in the eastern part of India and southern

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Bangladesh. Rice is the major crop in this delta, occupying about 98% of the cultivated area under rainfed conditions during the wet season (monsoon/*kharif*; June to December). Growing other crops is difficult during this period because of flooding caused by heavy rain. The productivity of rice is low (<2 t ha^{-1}) due to common biotic and abiotic stresses, preferred use of long-duration traditional landraces or old varieties, and suboptimal agronomic practices in the nursery and the main field. Besides submergence and stagnant flooding, rice production in these coastal deltas is also challenged by other factors, including nutrient limitations, salinity, drought, and pests and diseases (Ismail and Tuong, 2009). Thus, a combination of high-yielding, stress-tolerant varieties and good management practices is necessary to boost current productivity levels.

A widespread constraint for rice production in the delta is the incidence of complete submergence for 1–2 weeks and/or stagnant floods (SF, 25–50 cm) for most of the season caused by excessive rain or overflowing rivers, resulting in severe damage to rice (Das, 2012). Farmers' current varieties are not adapted to such conditions and their yields are severely reduced because of high mortality, suppressed tillering, reduced panicle size, and high sterility (Wassmann et al., 2009). However, recently released varieties in India, which are submergence-tolerant (contain the *SUB1* gene; e.g., Swarna-Sub1), can substantially increase rice productivity in such flood-affected areas (Singh et al., 2009, 2014; Mackill et al., 2012; Ismail et al., 2013). Sub1 rice genotypes slow down their growth when inundated, resulting in their survival and fast recovery when floodwaters recede. Other genotypes, such as Amal-Mana, elongate when flooded, making them more suited to areas where shallower floodwater stagnates in the field for several weeks or months (Singh et al., 2011; Sarkar and Bhattacharjee, 2012; Vergara et al., 2014; Kato et al., 2014). The yield advantage of these stress-tolerant varieties is greater when exposed to stresses and in most cases; they produce higher yields over older varieties in the absence of stress (Singh et al., 2009, 2013, 2014; Ismail et al., 2013).

The general management recommendations of rice nursery for favorable conditions are well established, usually involve seeding density of 50–100 g m^{-2}, nutrient application through inorganic as well as organic sources and transplanting younger seedling (Rice Knowledge Bank; http://www.knowledgebank.irri.org). However, these recommendations need to be validated for less favorable areas where growing conditions are mostly different. Generally, crop establishment is a major constraint to productivity in all areas affected by early incidences of abiotic stresses, such as drought, flooding, and salinity, because seedlings are very sensitive to these stresses. An adaptive management strategy is the use of healthy seedlings grown in properly managed nurseries to ensure good crop stand. Practices such as optimum seeding density, proper seedling age, careful handling at transplanting, and balanced nutrient supply, were reported to help mitigate the adverse effects of floods and other abiotic stresses following transplanting (Ram et al., 2009; Ella and Ismail, 2006; Ella et al., 2011; Ismail et al., 2012; Sumon et al., 2013; Gautam et al., 2014; Bhowmick et al., 2014), however, the effectiveness of these practices have not been sufficiently validated for saline coastal areas. Integration of locally available organic sources of nutrients such as farmyard manure (FYM) with fertilizer recommendations was reported to be effective for rice in coastal areas (Sarangi et al., 2014). Use of healthy seedlings could improve the productivity of transplanted rice in saline coastal zones as high salinity stress retards elongation of transplanted seedlings and reduces nutrient availability during early growth. Age of seedlings at transplanting is particularly important for areas affected by salinity and floods because younger seedlings are more sensitive to both stresses. Results from drought stress affected areas in the mid-hills of Nepal highlighted the importance of good seedbed management and right seedling age, leading to significantly higher rice yields (Adhikari et al., 2013).

The present study was conducted to examine the effect of seed density, seedling age, and nursery nutrient management on seedling health, crop establishment and grain yield. We hypothesize that combining good nursery practices with tolerant varieties will enhance crop establishment and yield in these less favorable areas. The best nursery management options developed in on-station trials were subsequently validated over two successive years in farmers' fields with new stress-tolerant rice varieties.

2. Materials and methods

The studies were conducted at the Central Soil Salinity Research Institute Regional Research Station (CSSRI-RRS) at Canning Town (22° 15′ N, 88° 40′ E; 3.0 m above MSL) during the wet seasons of 2011 and 2012 (on-station) and in farmers' fields during the wet seasons of 2012 and 2013 (Table 1). The on-farm trials were conducted at eight locations spreading across two districts (North and South 24 Parganas) of West Bengal, India (Table 2). The soil in the station is heavy textured, with 40–43% clay, 10% sand, and 47–50% silt. The pH of the top soil varied from 5.8 to 7.1, with average bulk density of 1.49 and organic carbon concentration of 0.48%. The experimental area was mono-cropped with rice for the last three years preceding the trials.

The climate at the site is tropical monsoon with an average annual rainfall of 1802 mm, of which about 89% occurs in the monsoon season (June–October). Total seasonal rainfall was 1704, 1361, and 1936 mm for 2011, 2012, and 2013, respectively. Overall, the rainfall was well distributed during seasons and little rain was experienced during the maturity period (November and December). Maximum temperature varied between 25.6 and 33.3 °C, 25.2 and 35.1 °C, and 26.9 and 33.3 °C during 2011, 2012, and 2013, respectively. Minimum temperature was lowest in December (14.6, 13.7, and 14.5 °C) and highest in June (26.4, 27.6, and 26.6 °C) during the three respective years.

2.1. On-station trials

On-station experiments were conducted in a split-split-plot design using rice variety Amal-Mana (Table 1). Top-soil salinity (EC_e; electrical conductivity of saturated soil extract in the top 20 cm) was between 4.0 and 5.0 dS m^{-1}. The treatments used seedlings from two seed densities (D1: 40 and D2: 25 g m^{-2}) for the sub-plots, two seedling ages at planting (T1: 40-d and T2: 25-d) for the main plots, and four nutrient combinations of N–P_2O_5–K_2O kg ha^{-1} (N_1: 25–0–0, N_2: 50–30–15, N_3: 25–30–15, and N_4: 0–30–15) for the sub-sub-plots. Treatment N_1 represented farmer's practice of applying only some urea and FYM in nursery. In all plots, 5 t ha^{-1} of FYM were applied as basal. Sowing in the seedbed was staggered at 15-d intervals so that transplanting could be done on the same day. The full dose of phosphorus and potassium and 50% of nitrogen were applied as basal at sowing based on respective treatments. The rest of the nitrogen was applied in two equal splits at 15 d of sowing and 7 d before uprooting. The seedlings were transplanted on 1 August using 2 seedlings $hill^{-1}$ at spacing of 15 × 15 cm. All plots in the field received similar treatments, including FYM at 5 t ha^{-1} applied one month before transplanting and inorganic fertilizers at 50–20–10 kg N–P_2O_5–K_2O ha^{-1}. P and K were applied as basal before transplanting, whereas nitrogen in the form of urea was applied in three equal splits at 7 d after transplanting (DAT), at maximum tillering (45 DAT), and at initiation of flowering (75 DAT).

Growth measurements were made on ten randomly sampled seedlings from each treatment in the nursery at one week (1 wk), two weeks (2 wk) after sowing, and at transplanting time (25 and 40 d after sowing based on respective treatments). Number and area of