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 vigour 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-P₂O₅-K₂O 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-P₂O₅-K₂O + 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.

Keywords: Benefit/cost ratio; coastal zones; nursery management; rice varieties; stagnant flooding; seedling age; seed density; seedling vigour; submergence-prone lowlands

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 *Sundarban* area of the lower Gangetic delta, located in the eastern part of India and southern 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 ($< 2 \text{ t ha}^{-1}$) 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; Mackill et al., 2012; Ismail et al., 2013; Singh et al., 2014). Sub1 rice genotypes slow down their growth

77 when inundated, resulting in their survival and fast recovery when floodwaters recede. Other
78 genotypes, such as Amal-Mana, elongate when flooded, making them more suited to areas
79 where shallower floodwater stagnates in the field for several weeks or months (Singh et al.,
80 2011; Sarkar and Bhattacharjee 2012; Vergara et al., 2014; Kato et al. 2014). The yield
81 advantage of these stress-tolerant varieties is greater when exposed to stresses and in most
82 cases; they produce higher yields over older varieties in the absence of stress (Singh et al.
83 2009, Singh et al. 2013, Ismail et al. 2013, Singh et al, 2014)

84 The general management recommendations of rice nursery for favorable conditions
85 are well established, usually involve seeding density of 50-100 g m⁻², nutrient application
86 through inorganic as well as organic sources and transplanting younger seedling (Rice
87 Knowledge Bank; <http://www.knowledgebank.irri.org>). However, these recommendations
88 need to be validated for less favorable areas where growing conditions are mostly different.
89 Generally, crop establishment is a major constraint to productivity in all areas affected by
90 early incidences of abiotic stresses, such as drought, flooding, and salinity, because seedlings
91 are very sensitive to these stresses. An adaptive management strategy is the use of healthy
92 seedlings grown in properly managed nurseries to ensure good crop stand. Practices such as
93 optimum seeding density, proper seedling age, careful handling at transplanting, and balanced
94 nutrient supply, were reported to help mitigate the adverse effects of floods and other abiotic
95 stresses following transplanting (Ram et al., 2009; Ella and Ismail, 2006; Ella et al., 2011;
96 Ismail et al., 2012; Sumon et al., 2013; Gautam et al., 2014; Bhowmick et al., 2014),
97 however, the effectiveness of these practices have not been sufficiently validated for saline
98 coastal areas. Integration of locally available organic sources of nutrients such as farmyard
99 manure (FYM) with fertilizer recommendations was reported to be effective for rice in
100 coastal areas (Sarangi et al., 2014). Use of healthy seedlings could improve the productivity
101 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 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.

Table 1

Details of field experiments conducted at CSSRI-RRS Canning Town (on-station) and at farmers' fields (on-farm) during the wet seasons of 2011-2013.

Experiment and design	Treatments Details	
<i>On-station experiment (wet seasons of 2011 and 2012)</i>		
Experiment 1	Main-plot: Seedling age (T)	T1: 40 days (d), T2: 25 d;
Nursery management	Sub-plot: Seed density (D)	D1: 40 g m ⁻² , D2: 25 g m ⁻² ;
Split-split	Sub-sub plot: Nutrient Management (N)	N1: 25-0-0, N2: 50-30-15, N3: 25-30-15, N4: 0-30-15 kg N-P ₂ O ₅ -K ₂ O ha ⁻¹ ; FYM at 5 t ha ⁻¹ was applied uniformly to all plots.
<i>On-farm experiment (wet seasons of 2012 and 2013)</i>		
Experiment 2	Farmer's method of nursery management using local varieties	High seed density (> 75 g m ⁻²); fertilizer at 25-0-0 kg N-P ₂ O ₅ -K ₂ O ha ⁻¹ ; seedling age: 25- 30-d; varieties: Pratikshya, Pankaj, Mahsuri, Sabita and CR1017;
Nursery management	Farmer's nursery management with improved variety	As above except using Amal-Mana and Swarna-Sub1;
RBD	Improved nursery management with improved variety	Seed density: 25 g m ⁻² ; fertilizer at 50-30-15 kg N-P ₂ O ₅ -K ₂ O + 5 t FYM ha ⁻¹ ; seedling age: 40-d; varieties: Amal-Mana and Swarna-Sub1

Table 2

Details of locations, varieties, and plot sizes of on-farm trials conducted during 2012 and 2013 in the *Sundarbans* region of West Bengal, India.

Farmer*	Longitude	Latitude	Village	Improved variety	Farmer's variety	Plot size [§] (m ²)
District: South 24 Parganas						
F1	88°49'5"E	22°8'9"N	Dulki	Swarna-Sub1	Pratikshya	295
F2	88°49'10"E	22°8'12"N	Pakhiralay	Amal-Mana	CR 1017	140
F3	88°49'8"E	22°8'14"N	Pakhiralay	Swarna-Sub1	Pratikshya	238
F4	88°49'13"E	22°8'17"N	Pakhiralay	Amal-Mana	Pankaj	275
District: North 24 Parganas						
F5	88°49'12"E	22°23'51"N	Simulhati	Amal-Mana	Mahsuri	352
F6	88°49'26"E	22°23'48"N	Simulhati	Amal-Mana	Mahsuri	135
F7	88°49'21"E	22°23'47"N	Simulhati	Swarna-Sub1	Sabita	252
F8	88°49'16"E	22°23'50"N	Simulhati	Amal-Mana	Pankaj	110

*F1: Ratan Mondal, F2: Probhudhan Mondal, F3: Arun Mondal, F4: Achinta Mondal, F5: Birbal Sardar, F6: Ghanashyam Patra, F7: Hazra Singh, and F8: Nirapada Dayal

[§]plot size of each of 6 replication

The climate at the site is tropical monsoon with an average annual rainfall of 1,802 mm, of which about 89% occurs in the monsoon season (June-October). Total seasonal rainfall was 1,704, 1,361, and 1,936 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 to 33.3 °C, 25.2 to 35.1 °C, and 26.9 to 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 4.0-5.0 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-P₂O₅-K₂O kg ha^{-1} (N₁: 25-0-0, N₂: 50-30-15, N₃: 25-30-15, and N₄: 0-30-15) for the sub-sub-plots. Treatment N₁ 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-P₂O₅-K₂O ha^{-1} . P and K were

161 applied as basal before transplanting, whereas nitrogen in the form of urea was applied in
162 three equal splits at 7 d after transplanting (DAT), at maximum tillering (45 DAT), and at
163 initiation of flowering (75 DAT).

164 Growth measurements were made on ten randomly sampled seedlings from each
165 treatment in the nursery at one week (1w), two weeks (2w) after sowing, and at transplanting
166 time (25 and 40 d after sowing based on respective treatments). Number and area of green
167 leaves per seedling were recorded on five seedlings from each plot. Nitrogen concentrations
168 in leaves were determined following digestion in concentrated H₂SO₄ at 400 °C (Varley,
169 1966). The seedling vigour index (SVI) for different treatments was calculated at the time of
170 uprooting using the formula: $SVI = \text{seedling length (total shoot and root length)} \times \%$
171 germination, based on Abdul-Baki and Anderson (1973). Germination percentage was
172 determined in a petri dish using 1,000 seeds from each seed stock used in the experiment.
173 Total shoot and root lengths were measured for seedling length to calculate SVI. In coastal
174 areas, higher shoot length is necessary for survival when transplanting in flooded fields and
175 robust root helps in quick recovery after submergence.

176 Seedlings from all treatments and replications were uprooted separately and
177 transplanted in the main field following uniform management practices. Twelve hills from
178 each plot were randomly sampled at harvest to determine yield attributes. To determine the
179 panicle number per hill, only the panicle-bearing tillers were counted and averaged over 12
180 hills. Panicles were hand-threshed, filled (grains) and empty spikelets (chaff) were separated
181 by submerging threshed spikelets in tap water and the number of grains per panicle was
182 counted and averaged over 12 hills. All floating spikelets were considered empty. After
183 thoroughly drying the grains under the sun, 1,000-grain weight was recorded for each
184 treatment. From each net plot area of 20 m², grains were harvested, dried, and weighed, and
185 grain weight was adjusted to moisture content of 0.14 g H₂O g⁻¹ fresh weight.

2.2. On-farm trial

The objective of this study was to validate the improved nursery management practices identified on-station together with improved rice varieties (Amal-Mana and Swarna-Sub1) in natural farmers' fields. The farmers were selected in the target area based on land type and water depth suitable for each of the improved varieties. For Amal-Mana, five farmers having lowlands with usual standing water depth of 30-40 cm for most of the monsoon season (stagnant flood, SF) were selected, whereas, for Swarna-Sub1, only three farmers were chosen (Table 2), with lands of medium elevation and usually with 15-25 cm of standing water but regular flash floods (water depth exceeds 30 cm during this period, completely inundating the plants but for only a short duration) after transplanting, which adversely affects crop establishment (Fig. 1). During 2012, Amal-Mana experienced maximum submergence during early tillering, while Swarna-Sub1 experienced flash flood at active tillering stage. In 2013, Swarna-Sub1 was inundated during late tillering, whereas Amal-Mana experienced the deepest stagnant flooding both during active tillering and panicle initiation (Fig. 1).

Fig. 1. Water depth in (a) 2012 and (b) 2013 in farmers' fields during the growing period at different on-farm locations (F₁, F₃ and F₇ are farmers growing Swarna-Sub1 and F₂, F₄, F₅, F₆ and F₈ are growing Amal-Mana, Table 2) in West Bengal, India.

Each on-farm experiment was laid as a randomized block design (RBD) with six replications and three treatments—T1: farmer's nursery management (NM) with farmer's varieties (Table 2); T2: farmer's NM with improved varieties (Amal-Mana or Swarna-Sub1); and T3: improved NM with improved variety (Table 1). The varieties traditionally grown by farmers were mostly released during the 1980's except Pratikshya, which was released in 2005. The improved varieties recently developed for coastal lowland areas were released in 2008 (Amal-Mana) and 2009 (Swarna-Sub1) (Ismail et al., 2013). The improved nursery management practices using a seed density of 25 g m⁻², 40-d-old seedlings at transplanting, and a nutrient combination of 50-30-15 kg N-P₂O₅-K₂O ha⁻¹ + 5 t FYM ha⁻¹ were selected based on data from on-station trials. In all locations, the soil was initially saline (ECe of 4.02 to 4.79 dS m⁻¹) and slightly acidic (pH of 5.04 to 6.28). Nurseries were sown using certified seeds in mid-June and seedlings were transplanted in the last week of July using two

seedlings per hill spaced at 15 x 15 cm. Fertilizers were applied at 50-20-10 kg N-P₂O₅-K₂O + 5 t FYM ha⁻¹ uniformly in all farmers' fields during both years. The depth of water in the field (Fig. 1) was monitored using a meter stick installed in each plot. SVI, grain and straw yields were recorded following the methods used in on-station trials.

2.3. Statistical and economic analyses

The data were subjected to analysis of variance (Gomez and Gomez, 1984) using the MSTAT statistical package. Treatment means of on-station experiments were separated using least significant difference (LSD) tests and compared at $p < 0.05$ level of significance. The interactions of factors monitored in this study were found to be non-significant and were not reported. Mean data over the two years of study are presented for all parameters as no significant interactions were observed between treatments and years. The variety-wise means of the 3 combinations of treatments across two seasons were compared separately using the least significant difference (LSD) tests at $P \leq 0.05$. Each treatment value, therefore, represents a mean of 36 data points for trials using Swarna-Sub1 (3 on-farm trials with 6 replications in each trial) and 60 data point for trials using Amal-Mana (5 on-farm trials with 6 replications in each trial).

Economic evaluation of different treatments was based on total variable cost, gross return, gross margin, and benefit/cost ratio (BCR). Total variable cost included the costs of inputs (seed, fertilizer, and pesticides); labour (for land preparation, irrigation, fertilizer and pesticide application, harvesting, bundling, hauling, and threshing), and renting a power tiller for land preparation and a pump for irrigation. Gross returns were calculated by multiplying the amount of produce (grain and straw) by its corresponding price at harvest. The gross margin was computed by subtracting total variable costs from gross returns, and BCR was calculated by dividing gross returns by total variable costs. The economic analysis uses prevailing market prices of inputs, labour, and produce during 2013-14 in Indian Rupees (INR, ₹), which was then converted into US\$ using the conversion rate \$1 = ₹ 60.

3. Results

3.1. On-station trials for evaluation of nursery management practices

The dry weight of seedlings increased with age (Table 3) and it was highest at uprooting for 40-d-old seedlings (7.4 g per 10 seedlings). Seedling biomass was 91% higher under the low seed density of 25 g m⁻² compared with that of the higher seed density of 40 g m⁻². Among the nutrient levels, the highest dry weight of seedlings was observed with 50-30-15 kg N-P₂O₅-K₂O + 5 t FYM ha⁻¹ applied to the nursery. The dry weight per 10 seedlings was more than 100% higher with the 50-30-15 kg N-P₂O₅-K₂O + 5 t FYM ha⁻¹ treatment compared with the 25-0-0 kg N-P₂O₅-K₂O + 5 t FYM ha⁻¹.

Shoot length, root length, number of green leaves and leaf area per seedling were significantly higher in 40-d-old seedlings (Table 3). Average seedling shoot length was 46 and 63 cm for 25- and 40-d-old seedlings, respectively. Seedling root was 27% longer in 40-d- than in 25-d-old seedlings. Older (40 d) seedlings had more than 4 green leaves, whereas the 25-d-old seedlings had less than 4 leaves per seedling. Seedling shoot length, root length, number of green leaves, leaf area per seedling and leaf N concentration were higher with lower nursery seed rate (25 g m⁻²). The seedlings' leaf N concentration increased by 7.3% at seeding density of 25 g m⁻² compared with that at 40 g m⁻². The treatment combining 5 t ha⁻¹ FYM with 50-30-15 kg N-P₂O₅-K₂O ha⁻¹ in nursery improved shoot length, root length, number of green leaves, and leaf area per seedling and resulted in significantly higher leaf N concentration (1.93) than the other nursery nutrient treatments.

Fig. 2. Seedling vigour index under different combinations of nursery management practices in the on-station experiment at CSSRI-RRS, Canning Town, West Bengal, India. Data are means of the wet seasons of 2011 and 2012. Vertical bars indicate LSD at $P \leq 0.05$ for treatment means.

[T: Seedling age (T1 = 40-d, T2 = 25-d), D: seeding rate (D1 = 40 g m⁻², D2 = 25 g m⁻²), N: nutrient management (N₁ = 25-0-0, N₂ = 50-30-15, N₃ = 25-30-15 and N₄ = 0-30-15 kg N-P₂O₅-K₂O ha⁻¹; in all plots, 5 t ha⁻¹ FYM were applied as basal)]

SVI (Fig. 2) was highest (7,998) with the combination of 40-d-old seedlings (T1), 25 g m⁻² seed rate (D2), and nutrient application of 50-30-15 kg N-P₂O₅-K₂O ha⁻¹ with 5 t ha⁻¹ FYM (N₂); and lowest (4,595) for 25-d-old seedlings (T2), 40 g m⁻² seed rate (D1), and 0-30-15 kg N-P₂O₅-K₂O ha⁻¹ (N₄).

Table 3

Effects of nursery management practices on seedling growth in the nurser, in the on-station experiment at CSSRI-RRS, Canning Town. Shoot length, root length, number of green

leaves, leaf area and leaf N concentration were determined when plants were uprooted for transplantation. Data are mean of 2011 and 2012 wet seasons.

	Dry weight (g 10 seedlings ⁻¹) [§]			Shoot Length (cm)	Root length (cm)	No. of green leaves seedling ⁻¹	Leaf area (cm ² seedling ⁻¹)	Leaf N concentr ation (%)
	1 st wk	2 nd wk	Up- rooting					
Seedling age								
40-d	0.45	0.79	7.74	62.6	16.1	4.4	41.9	1.55
25-d	0.46	0.70	3.30	45.9	12.7	3.9	39.0	1.56
LSD _{0.05}	ns ^a	0.09	0.29	1.0	0.6	0.4	1.4	Ns
Seeding rate								
40 g m ⁻²	0.41	0.69	3.79	53.3	13.9	3.8	33.8	1.50
25 g m ⁻²	0.50	0.80	7.25	55.2	14.9	4.4	47.0	1.61
LSD _{0.05}	0.04	0.02	0.31	1.1	0.5	0.1	1.1	0.02
Nutrient management (kg N-P ₂ O ₅ -K ₂ O ha ⁻¹ + 5 t ha ⁻¹ FYM)								
25-0-0	0.41	0.74	4.46	51.3	13.1	4.1	32.4	1.36
50-30-15	0.56	0.81	9.19	60.0	15.5	5.2	58.7	1.93
25-30-15	0.44	0.83	4.48	54.6	14.7	3.7	37.8	1.59
0-30-15	0.42	0.61	3.96	51.0	14.3	3.5	32.8	1.35
LSD _{0.05}	0.03	0.05	0.46	1.46	0.5	0.3	1.4	0.02

* ns = not significant

[§]1 wk, 2 wk, and uprooting are observations at one week, two weeks, and at time of uprooting for the nursery for transplanting, respectively.

Nursery management options had a significant effect on yield and yield attributes except for 1,000-grain weight (Table 4). However, all interactions of seed rate, nutrient options, and seedling age were not significant for yield attributes and grain and straw yields. The number of tillers hill⁻¹ and panicles hill⁻¹ were significantly higher when transplanting 40-d-old seedlings than 25-d-old seedling. Low density seeding produced 6% more tillers and panicles per hill than high density seeding. The number of tillers and panicles per hill also increased significantly with the application of 50-30-15 kg N-P₂O₅-K₂O ha⁻¹ + 5 t FYM ha⁻¹ in nursery than with other nutrient treatments. Increase in panicles hill⁻¹ is mainly due to commensurate increase in tillers hill⁻¹. Grains per panicle increased by about 3% at lower

nursery seeding rate over the high rate. Similar effects were also observed with transplanting 40-d-old seedlings compared with 25-d-old seedlings. The number of grains per panicle was lowest in the treatment involving no or low nitrogen, but increased significantly when nitrogen application was increased from 0 to 50 kg ha⁻¹ with similar P and K.

Table 4

Grain yield and yield components of variety Amal-Mana as affected by nursery management in on-station experiment at CSSRI-RRS, Canning Town. Data are means of 2011 and 2012 wet seasons.

	Tillers hill⁻¹	Panicles hill⁻¹	Grains panicle⁻¹	1000 grain weight (g)	Grain yield (t ha⁻¹)	Straw yield (t ha⁻¹)
Age of seedlings						
40-d	11.5	9.7	121.5	29.9	4.27	7.83
25-d	9.7	8.3	118.8	29.8	3.50	7.11
LSD _{0.05}	0.4	0.4	1.4	ns*	0.35	0.34
Seeding rate						
40 gm ⁻²	10.3	8.7	118.4	29.8	3.73	7.06
25 gm ⁻²	10.9	9.2	121.9	29.9	4.04	7.88
LSD _{0.05}	0.3	0.4	2.2	ns	0.19	0.48
Nutrient management (N-P₂O₅-K₂O kgha⁻¹+ 5 ha⁻¹ FYM)						
25-0-0	9.7	8.0	113.3	29.9	3.45	6.84
50-30-15	11.8	10.2	130.1	29.9	4.57	8.61
25-30-15	10.8	9.3	121.1	29.8	3.96	7.22
0-30-15	10.1	8.4	116.0	29.8	3.56	7.21
LSD _{0.05}	0.3	0.3	2.0	ns	0.24	0.59

*ns = not significant

Transplanting 40-d-old seedlings produced 22% higher grain yield than transplanting 25-d-old seedlings (Table 4). Grain and straw yields increased by 8.3% and 11.6%, respectively, under low nursery seeding rate; and were significantly higher with the application of 50-30-15 kg N-P₂O₅-K₂O ha⁻¹ than other nursery nutrient management treatments. However, all interactions were not significant.

318

319 The cost of production increased by US\$10 ha⁻¹ when higher seeding rate was used in
 320 the nursery (Table 5), \$20 ha⁻¹ when transplanting younger seedlings, and by \$6 ha⁻¹ with
 321 application of 50-30-15 kg N-P₂O₅-K₂O ha⁻¹, compared with 25-0-0 kg N-P₂O₅-K₂O ha⁻¹.
 322 Gross return increased by 21% when a lower seeding rate was used in the nursery. The
 323 highest gross return (\$1,251 ha⁻¹) was observed when applying 50-30-15 kg N-P₂O₅-K₂O ha⁻¹
 324 to the nursery, and the lowest (\$947 ha⁻¹) with 25-0-0 kg N-P₂O₅-K₂O ha⁻¹, which was at par
 325 with the application of 0-30-15 kg N-P₂O₅-K₂O ha⁻¹. The gross margin was \$222 ha⁻¹ higher
 326 when transplanting 40-d-old seedlings than with using 25-d-old seedlings. The gain was
 327 higher (gross margin increase by 26.8%) when transplanting seedlings produced using lower
 328 seeding rate. The gross margin was also significantly influenced by nursery nutrient
 329 management, being highest for the use of 50-30-15 kg N-P₂O₅-K₂O ha⁻¹ followed by 25-30-
 330 15 kg N-P₂O₅-K₂O ha⁻¹ and the lowest with 25-0-0 kg N-P₂O₅-K₂O ha⁻¹. Consequently, the
 331 highest BCRs of 1.82, 1.72, and 1.91 were observed when transplanting 40-d-old seedlings,
 332 using a seed density of 25 g m⁻², and applying 50-30-15 kg N-P₂O₅-K₂O ha⁻¹, respectively.
 333 However, all interactions of seed rate, nutrient options, and seedling age were not significant
 334 for all parameters included in the economic analyses.

335

336 **Table 5**

337 Economic analyses (US\$ ha⁻¹) of nursery management practices in the on-station experiment
 338 at CSSRI-RRS, Canning Town, averaged over 2011 and 2012 wet seasons.

339

	Cost of cultivation	Gross return	Gross margin	BCR
Age of seeding				
40-d	643	1165	524	1.82
25-d	664	965	302	1.45
LSD _{0.05}	0.2	84	84	0.13

Seed density				
40 g m ⁻²	658	1022	364	1.56
25 g m ⁻²	648	1109	461	1.72
LSD _{0.05}	0.1	46	46	0.07
Nutrient management (N-P ₂ O ₅ -K ₂ O kg ha ⁻¹ + 5 t ha ⁻¹ FYM)				
25-0-0	649	947	299	1.47
50-30-15	655	1251	596	1.91
25-30-15	654	1081	427	1.66
0-30-15	653	981	328	1.51
LSD _{0.05}	0.3	62	62	0.10

3.2. On-farm evaluation of improved nursery management

The highest mean SVI (5,423) was observed with improved nursery management and improved stress-tolerant varieties Amal-Mana and Swarna-Sub1, and the lowest SVI (3,675) was with farmers' variety and nursery management (Fig. 3). Use of an improved variety with farmers' practices had an SVI of 4,824, indicating that replacing current farmers' varieties alone will result in substantial improvements in seedling vigour and, subsequently, in crop establishment in coastal saline areas. The mean SVI values with farmer's nursery management and improved nursery management were, respectively, 23% and 21% higher for Amal-Mana than for Swarna-Sub1, resulting in better performance of Amal-Mana in fields affected by stagnant floods.

Fig. 3. Seedling Vigour Index as influenced by nursery management practices. Data are means of the 2012 and 2013 wet seasons. Vertical bars indicate LSD at $P \leq 0.05$ for treatment means. NM = nursery management.

The mean grain yield with improved nursery management combined with an improved variety was 3.88 t ha^{-1} , which is 36.6% higher than farmer's nursery management and farmer's variety, and 10.2% higher than farmer's nursery management and improved variety (Fig. 4a). The yield advantages of Swarna-Sub1 and Amal-Mana with improved nursery management were 23% and 47% higher than from farmer's nursery management and farmer's variety, respectively. Swarna-Sub1 performed better than Pratikshya and Sabita in areas affected by flash floods, whereas the taller variety Amal-Mana performed well in fields affected by stagnant flooding, out-yielding CR1017, Pankaj, and Mahsuri, which are traditionally grown in the coastal areas of West Bengal. Similarly, the straw yields (Fig. 4b) increased significantly with improved varieties and nursery management (7.09 t ha^{-1}) as compared with improved varieties and farmer's nursery management (6.58 t ha^{-1}) or with both farmer's varieties and nursery management (5.28 t ha^{-1}).

Fig. 4. (a) Grain and (b) straw yields as influenced by nursery nutrient management practices in on-farm trials. Data are means of the wet seasons of 2012 and 2013. Vertical bars indicate LSD at $P \leq 0.05$ for treatment means. NM= nursery management.

4. Discussion

Knowledge about the best agricultural practices that favor the expression of tolerance of abiotic stresses of the new tolerant varieties are presently inadequate. This study is an

attempt to develop a set of improved management practices for rainfed lowland stress tolerant rice grown in salt and flood affected coastal areas.

4.1. Effects of seed density and seedling age on seedling growth and crop performance

Seeding density in the nursery significantly affected seedling vigour. Seedling biomass, shoot and root length, number of green leaves per seedling, leaf area, and leaf N concentration significantly improved when the lower seed rate of 25 g m⁻² was used (Table 3). Providing more space for seedlings in the nursery enhanced seedling growth, probably enhancing light interception, and nutrient and moisture uptake. Lal and Roy (1996) reported that low seeding density of 50 g m⁻² in the nursery produced significantly taller plants with more leaves as compared with 75 and 100 g m⁻² seeding rate. Ram et al. (2009) reported that lower seed density in the nursery (50 g m⁻² compared to 100 g m⁻²) produced vigorous seedlings with higher shoot biomass and shoot carbohydrate content. High concentrations of non-structural carbohydrates in stems are known to be associated with higher tolerance of flooding and early recovery in rice (Das et al., 2009; Singh et al., 2014; Kato et al., 2014). Reduction of seed density to 25 g m⁻² will therefore, improve seedling root growth, which could result in better nutrient uptake and seedling growth.

Seedlings produced with wider spacing established faster after transplanting, had better survival after 10 to 15 d of complete submergence, and showed better recovery following submergence (Ram et al., 2009). In this study, sowing Amal-Mana, at nursery seed rate of 25 g m⁻² resulted in 6% more panicles hill⁻¹ and 3% more grains panicle⁻¹, leading to 8% and 12% higher grain and straw yields, respectively. A similar study by Sumon et al. (2013) also demonstrated beneficial effects of healthy and more robust seedlings produced from lower seed density in the nursery. They observed that the lower seeding rate of 25 g m⁻² produced 7-21% higher grain yields in BRRI dhan51 as compared with a seeding rate of 40 g m⁻². Mustari et al. (2013) found that seedlings from nurseries with

low seeding density (25 g m⁻² versus 40 g m⁻²) were more vigorous and had a yield advantage ranging from 29% to 141% for different varieties and submergence conditions, with greater response in tall, submergence-intolerant varieties such as Mahsuri. Better stress tolerance and higher yields due to healthy and vigorous seedlings were also reported by TeKrony and Egli (1991), Ella and Ismail (2006), Singh et al. (2012), and Adhikari et al. (2013).

Optimal transplanting age is dependent on field conditions at transplanting; with younger seedlings favored when conditions are ideal and hydrology is well controlled, as in irrigated ecosystems. Contrary to this notion, our data showed that growth of 40-d-old seedlings was significantly better than that of 25-d-old seedlings in these less favorable areas. This was reflected in better shoot biomass (134%), shoot length (35%), root length (27%), number of green leaves per seedling (13%), and leaf area (8%). Transplanting 40-d-old seedlings also increased panicles per hill and grains per panicle, leading to a 22% higher grain yield. Older seedlings were taller, sturdier and healthier; as a result, they could cope better with deeper water prevalent in coastal rainfed, low-lying areas. Transplanting of 8 d to 12 d old seedlings as recommended in the System of Rice Intensification (Stoop et al., 2002) for favorable areas is therefore not adequate in systems without water control, un-leveled fields, and sub-optimal soil conditions. Taller seedlings are necessary to keep sufficient portion of the plant above the floodwater.

However, there are trade-offs when seedlings stay too long in the nursery. The primary tiller buds on the lower nodes of the main culm often degenerate (Mobasser et al., 2007), resulting in reduced tillering after transplanting. The same authors reported that number of panicles per m² was highest with 45-d-old seedlings; but grain yield was higher when transplanting 35-d-old seedlings. Similarly, Amin and Haque (2009) reported that 35-d-old seedlings were better than younger (15- and 25-d-old) or older (45-d-old) ones. The better

performance of older seedlings (35- to 45- d-old as compared with 25- to 30-d-old) was also reported by Channabasappa et al. (1998), Alam et al. (2002), Ella and Ismail (2006), Adhikari et al. (2013), Sumon et al. (2013), and Bhowmick et al. (2014) in less favorable conditions. Older seedlings had higher dry biomass and carbohydrate storage at transplanting. Consequently, they were more tolerant of submergence and waterlogging in the field (Ella and Ismail, 2006; Bhowmick et al., 2014). Also, older seedlings are less sensitive to salinity (Ram et al., 2009) and farmers often transplant older seedlings (>40 d) if rainfall is delayed (Subedi, 2013).

4.2. Effects of nursery nutrient management on seedling growth and crop performance

Applying fertilizers in the seedbed had several advantages. In the relatively small area of the nursery, even small amounts of fertilizers can make a difference, and healthier seedlings cope better with the transplanting ‘shock’ and perform better when conditions are suboptimal. And fertilizer use in the small area of the seedbed is more affordable for resource-limited. In this study, the application of inorganic and organic fertilizers (50-30-15 kg N-P₂O₅-K₂O ha⁻¹ + 5 t FYM ha⁻¹) in the seedbed resulted in better seedling growth, higher leaf nitrogen concentration, and higher grain yield in the main field (Table 4). Ros et al. (2003) as well as Sharma and Ghosh (1999) concluded that the response of rice yield to improved nursery nutrition is largely due to increased seedling vigour and the increase in seedling nitrogen concentration. Higher leaf N concentration in rice seedlings improved growth of leaf and root apices immediately after transplanting and hastened recovery. Enriching nursery seedbeds with N, P and Zn along with FYM, improved seedling vigour relative to the unfertilized control and resulted in 10-30% higher shoot carbohydrate concentration before transplanting (Ram et al., 2009). The nutritional status of seedlings just before transplanting can be of immense importance, especially when plants are subjected to

submergence during early growth stages. Farmers' practice of applying only N fertilizers in the nursery to produce taller and greener seedlings may not have a positive effect in flood-prone areas because high N content in transplanted seedlings reduces survival and recovery growth (Ella and Ismail, 2006). However, when N is applied with P (Jackson and Ram, 2003; Gautam et al., 2014) and micronutrients such as Zn (Ella and Ismail, 2006), it improves seedling vigour and enhances tolerance to abiotic stresses. The beneficial effects of higher application of N, P, and Zn in the nursery (up to twice the recommended dose of 48-44-11 kg N-P₂O₅-ZnO ha⁻¹), along with 10 t ha⁻¹ FYM, was also demonstrated in gypsum-amended sodic soils (Yaduvanshi and Sharma, 2012). Ella and Ismail (2006) observed poorer plant survival if high N was applied just before transplanting compared with early N application, irrespective of the genotypes' tolerance level. Application of P, either alone or together with N, improved the survival of plants in P-deficient soils after 12 d of complete submergence.

Thus, adequate nursery fertilizer rate and type depend on various factors such as initial soil fertility, application of organic nutrient sources, genotype tolerance of anticipated stresses, seeding rate in the nursery, and abiotic stresses in the field after transplanting. For transplanted rainfed lowland rice in the mid-hills of Nepal, the recommended N rate for the nursery is 30 kg ha⁻¹ (Subedi, 2013). Experiments by Panda et al. (1991) showed that grain yield increased by 20% with the N rate increase from 0 to 100 kg N ha⁻¹ in the rice nursery before transplanting. No significant effect of increasing the nursery N dose from 60 kg to 120 kg ha⁻¹ was reported by Singh (1999) at Kharagpur in West Bengal. Our results did confirm beneficial effects of balanced nursery fertilizer rates at low to medium levels at the study sites (Table 4 and 5). And adding organic sources such as FYM not only supplies macro nutrients but also essential micronutrients such as S, Fe, Mn, Cu, and Zn (Maskina et al., 1985).

4.3. *Response of stress-tolerant rice varieties to improved nursery management under field conditions*

Improved rice varieties are a key component for high and stable yields in rainfed delta environments. But their suitability depends on several factors, including input requirements and response, growth behavior and adaptation to prevailing biotic and abiotic stresses (Alam et al., 2012). New varieties such as Swarna-Sub1 and Amal-Mana outperformed the current farmers' varieties, mainly because of their better tolerance to complete submergence and stagnant floods. Swarna-Sub1 is submergence-tolerant and can produce 1.0 to 3.5 t ha⁻¹ more grain yield than sensitive varieties, depending on the stage at which submergence occurred, the duration of submergence, and the conditions of the floodwater (Das et al., 2009; Sarkar et al., 2009; Ismail et al., 2013). In the on-farm study conducted during the wet season of 2012 and 2013, varieties traditionally grown by farmers performed poor when flash-flooding occurred. At these sites, Swarna-Sub1 showed a yield advantage of up to 0.82 t ha⁻¹, with an average of 0.75 t ha⁻¹. Similarly, Amal-Mana had an average yield advantage of 1.22 t ha⁻¹ (range of 0.87 to 2.22 t ha⁻¹) across the five sites where stagnant flooding was experienced during most of the season (Fig. 1). However, Swarna-Sub1 is not adapted to long-term stagnant flooding prevalent in low-lying areas in the coastal zones (Singh et al., 2011; Vergara et al., 2014). In such conditions, the tall, salt-tolerant variety Amal-Mana outperformed traditionally grown varieties because of its ability to partially elongate under stagnant floods.

Our results indicated that replacing current farmers' varieties could improve rice production in coastal saline areas. But combining an improved variety with improved management resulted in higher yields and revenues. Improved management practices could also improve yield of the current farmers' varieties, but this was not evaluated in this study, given the urge for farmers to replace their existent varieties with stress tolerant ones. The

mean grain yield with improved nursery management and improved variety was 37% higher than farmer's practice, and 10% higher than farmer's nursery management and improved variety. Purushottam et al. (2012) found that grain yield in a rice-wheat system did only significantly increase when improved varieties were combined with improved crop establishment methods. Grain yield and economic gains were further enhanced when balanced fertilizer was used. The mean benefit:cost (B:C) value of promising nursery management combinations in our study was around 1.8 (Table 6). Reddy and Reddy (1992) suggested that B:C values ≥ 2 are necessary for technology adoption but a benefit:cost ratio above 1.5 has been considered economically viable for an agricultural enterprise, especially when the investments are small (Makarim et al., 2002). Combining good nursery management with high-yielding, stress-tolerant varieties could therefore improve system productivity and farmers' income in tropical coastal zones, where abiotic stresses like flash floods, stagnant flooding, and salinity are common.

5. Conclusions

This study showed that use of balanced nutrients and lower seeding rate in the nursery produced healthier and more vigorous seedlings that withstood floods and salinity better than seedlings produced through traditional farmers' practices. Good seedling vigour in the nursery ensured faster recovery and growth and higher yield in the transplanted rice systems when abiotic stresses are anticipated. The highest benefit:cost ratios were attained when transplanting 40-d-old seedlings produced using 25 g of seed per m² and with application of 50-30-15 kg ha⁻¹ N-P₂O₅-K₂O + 5 t FYM ha⁻¹, respectively. Application of a small amount of nutrients at 5-3-1.5 kg N-P₂O₅-K₂O + 500 kg FYM in a nursery area of 1,000 m², enough to produce seedlings for 1 ha, can increase grain yields by up to 30% over current farmers' practice. These cost-effective nursery management options have great potential to enhance

yield in coastal areas affected by salt stress and could help cope with stagnant as well as
flash flood incidences. The results of this study can effectively be recommended for rainfed
lowlands of West Bengal and for other areas in adjoining coastal states of India,
Bangladesh, Vietnam, and Myanmar that have similar ecologies.

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