Indian Journal of Agronomy **70** (2): 143–149 (June 2025)
DOI: 10.59797/ija.v70.i2.5595

Research Paper

Low-cost inputs for enhancing yield, economics and water productivity of transplanted rice under shallow lowland

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Received: November 2024; Revised accepted: May 2025

ABSTRACT

Producing robust seedlings in the nursery and transplanting them at the optimal age significantly enhances transplanted rice yield and profitability. Seed priming with appropriate bio-control agents followed by sowing at optimum density in the nursery produces healthy and vigorous seedlings. A field experiment was conducted for two years 2020 and 2021 to evaluate the bio-control agents, seeding density and optimum age of seedlings to achieve the potential yield of transplanted rice under shallow low land. The study employs split-split plot design with three factors: Main plots (seed treatments; S_1, *pseudomonas* @ 10 g/kg of seed; S_2, *trichoderma* @ 10 g/kg of seed and S_3, no seed treatment), subplots (seeding density; D_1, 40 g/m^2, D_2, 50 g/m^2 and D_3, 60 g/m^2) and sub-sub plots (age of seedlings at transplanting; A_1, 42 days and A_2, 21 days). Seed treatment with *Trichoderma* (NRRI formulation) resulted in the production of seedlings having higher length: biomass ratio (55.0) and an increase in the grain, straw yield and gross return by 14.0, 12.3 and 14.1%, respectively, over the control. Transplanting of young seedlings (21 days) resulted in significantly higher average gross return of ₹123.7 × 10^3/ha, B: C ratio (2.09) and economic water productivity (₹15.09/m^3). The use of 21-day-old seedlings reduced the cost of production of transplanted rice by 10.5% as compared to 42-day-old seedlings. Hence, it is recommended to treat rice seeds with *Trichoderma* @ 10 g/kg of seed, maintain a low seeding density (40–50 g/m^2) at the nursery and transplant 21 old days seedlings for realising yield potential of transplanted rice under shallow lowland.

Key words: Age of seedlings, *Pseudomonas,* Seedling density, *Trichoderma*, Water productivity, Yield

Rice is the leading cereal crop of India and plays an important role in the food security of the nation. The production of rice has to be enhanced with available reduced resources like water and land to feed the growing population under the climate change scenario. During the Green Revolution era, the adoption of high-yielding varieties with judicious water and nutrient management practices resulted in a substantial increase in rice production. Research institutes involved in rice breeding have developed several high yielding varieties suitable for different eco-regions and seasons. The production potential of newly developed rice varieties has to be realized with appropriate management practices so that it will enhance rice production at reduced cost and minimum deterioration to the natural resources.

Producing healthy and vigorous seedlings at a nursery and transplanting them at optimal age are considered as non-monetary inputs which significantly influences the yield and economics of transplanted rice (Bommayasamy *et al.,* 2010; Dass *et al.,* 2015). Seed priming with suitable bio-control agents is a simple and low-cost technology to improve the seedling vigour and seed health and ultimately increases the yield of several crops (Somasundaram and Bhaskaran, 2017). Several workers found that seed treatment with *Trichoderma and Pseudomonas* formulations provided a good alternative to chemical seed treatment in terms of disease control and enhancement in grain yield. There is an increasing trend in the use of biological seed treatments to avoid adverse impacts on human health and ensure a better environment (Lamichhane *et al*., 2022).

The seeding density in the nursery influences the seedling quality which results in better plant establishment with reduced mortality of seedlings (Shaikh *et al*., 2021). Practices of proper nursery management with appropriate seedling density produce healthy seedlings which ensures better rice crop establishment and crop yield. Well-nursed rice seedlings resulted in higher grain yield (Sarangi *et al.,* 2015). Early seedling vigour and its high photosynthetic production capacity were important characteristics for

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achieving a high yield of transplanted rice. The age of the seedlings at transplanting directly influences the crop establishment and grain yield of rice (Singh *et al*., 2018; Virk *et al*., 2021). The primary tiller buds on the lower nodes of the main culm became degenerated leading to reduced tiller production under delayed transplanting reduces the vegetative and reproductive period of the crop, and thus has detrimental impacts on grain yield (Liu *et al*. 2017). Transplanting of young seedlings was one of the no-cost inputs for sustainable rice yield. The optimum age of seedlings at the nursery varies with the duration of the varieties and season (Singh *et al*., 2018). By considering these, seed treatment with bio-agents, sowing seeds at various seeding densities at nursery and different ages of seedlings at transplanting were evaluated for maximizing the grain yield of transplanted rice under shallow lowland ecology.

MATERIALS AND METHODS

A field experiment was carried out at the experimental farm of ICAR-National Rice Research Institute, Cuttack (20.5^0 N, 86^0 E and 23.5 m above mean sea level) located in the 'Eastern and Southern Central Agro-climatic Zone' of Odisha, India during *Kharif* season of 2020 and 2021. The soil of the experimental field was sandy clay loam in texture (50.3% sand, 18.3% silt and 31.4% clay), slightly acidic with pH 6.4, total carbon 0.72%, available nitrogen 208 kg/ha; available P 17.6 kg/ha and available K 123 kg/ha. The rice crop received an average rainfall of 1122 mm from sowing at nursery to harvesting.

The experiment was arranged in a split-split plot design with three replications. The treatments consist of 3 seed treatments in main plots (S_1: *Pseudomonas* @ 10 g/ kg of seed, S_2: *Trcichoderma* @ 10 g/ kg of seed and S_3: no seed treatment), 3 seeding densities in subplots (D_1: 40 g/m^2, D_2: 50 g/m^2 and D_3: 60 g/m^2) and 2 age of seedlings at transplanting in sub-sub plots (A_1: 42 days and A_2:21 days).

The seeds of rice variety 'CR Dhan 314' were treated with *Pseudomonas* @ 10 g/ kg of seed, *Trichoderma* @ 10 g/ kg of seed and seeds without any treatment were sown during the first week of June and the last week of June at an interval of 21 days in the dry nursery with a seeding density of 40, 50 and 60 g/m ^{2}. The transplanting of 21- and 42-day old seedlings, at the rate of 2 seedlings per hill, was done on July 19th in both years.

The recommended dose of fertilizers were applied at the rate of 80- 40- 40 kg N-P-K/ha in the form of urea, di-ammonium phosphate (DAP) and muriate of potash (MOP), respectively. One-third of the quantity of nitrogen (N) and the full amount of phosphorus and 50% of potassium was applied as basal, one-third of N was applied at tillering and the rest one-third of N and 50% of K_2O were applied at the panicle initiation stage of the crop. Desired intercultural operation and need-based insect pest control practices were followed to raise the crop.

Ten seedlings from each treatment in the nursery were uprooted at transplanting and average seedling height and weight were recorded. The ratio of seedling height to weight was computed. The observation on seedling mortality was recorded at 7 days after transplanting and seedling mortality (%) was computed by the formula given as follows:

Seedling mortality (%) = [(Dead seedlings after 7 days of transplanting in one square meter)/ (Total number of seedlings planted in one square meter)] × 100.

The observations on weeds were recorded from each treatment before employing manual weeding at 20 DAT. The weeds were separated as grasses, broadleaved weeds and sedges. Different species of weeds were also counted from a one-meter area of each plot. Relative densities of weeds were computed.

The observations for various growth attributes such as number of tillers/ m^2, plant height, days to 50% flowering, and days to maturity were recorded as per the standard procedure. Data on grain yield and yield attributes were recorded at harvest. The number of panicles per unit area, grains per panicle, chaffy grains per panicle, grain yield, and straw yield were recorded. Test weight was computed by weighing 1,000 filled grains from the sample. The Harvest index was computed from economic yield and total biological yield. Economics were computed based on the Minimum Support Price (MSP) for grain and the local market price for other inputs used. The cost of production is computed (/kg) by dividing the cost of cultivation of one hectare of crop (/ha) by the grain yield (kg/ha).

Physical water productivity was calculated by dividing grain yield (kg/ha) by the water used (m^3). The water used is the sum of irrigation water and effective rainfall, which was estimated by the procedure suggested by Ali and Mubarak (2017). The economic water productivity was calculated by dividing gross return (/ha) by the water used. The data were analyzed statistically in MS-Excel with a split-split design as per standard procedure, following Analysis of Variance (ANOVA). The significance was tested at a 5% level of probability.

RESULTS AND DISCUSSION

Seedling character at the time of transplanting

The effect of seed treatment, seedling density and age of seedlings on seedling length to seedling biomass ratio is presented in Fig. 1. Seed treatment with *Trichoderma* NRRI formulation produced healthy seedlings with a 4.6% higher value of seedling length to seedling biomass ratio compared to control. *Trichoderma* being a rhizospheric microorganism produces IAA (Indole-3-Acetic Acid)

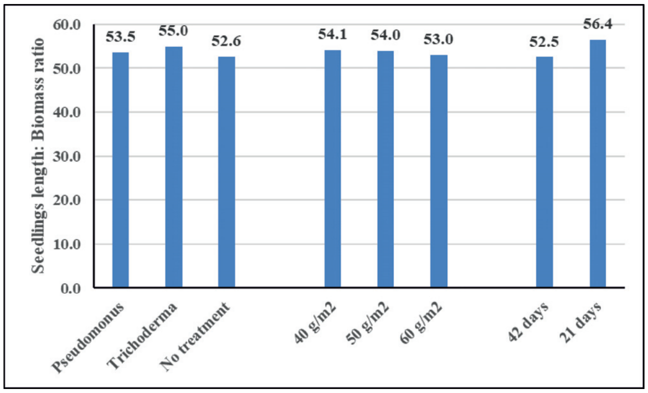

Fig. 1. Effect of seed treatment, seedling density and age of seedlings on seedling length to seedling biomass ratio

hormone which helps the production of healthy and vigorous seedlings (Anhar *et al.,* 2019). Doni *et al*. (2014) have also reported seed treatment with *Trichoderma* spp. Significantly increased rice seedling growth, germination rate, vigour index and speed of germination. Sowing of seeds at lower density in the nursery resulted in healthy seedlings having a higher value of seedling length to seedling biomass ratio (54.1). Though the height of seedlings and biomass increased with the age of seedlings, 21 days of young seedlings resulted higher value (56.4) of seedling length to seedling biomass ratio as compared to old seedlings (52.5).

Seedling mortality

The seedling mortality of transplanted seedlings is presented in Table 1. The transplanting of 42-day seedlings registered a higher percentage (11.29%) of seedling mortality compared to 21-day-old seedlings (4.92%). Seed treatment with bio-control agents significantly recorded the lowest percentage of seedling mortality (7.42% and 7.82% under S_1 and S_2, respectively) as compared to no seed treatment (9.08%). Rice seedling mortality rate is significantly influenced by seedling age due to the physiological and structural characteristics of the seedlings at the time of transplanting. Younger seedlings typically have more active meristematic tissues, higher regenerative capacity, and a stronger ability to establish themselves in new environments. In contrast, older seedlings often experience higher transplanting shock due to their more developed root systems being more prone to damage, reduced vigour, and slower recovery post-transplantation. The lower seedling mortality rate in younger seedlings can be attributed to their better resilience in shallow water, tolerance to high temperatures, and quicker recovery from transplanting shock (Virk *et al*., 2021). Seed treatment with bio-control agents is known for their ability to promote plant growth, suppress soil-borne pathogens (Harman *et al*., 2004), and improve nutrient uptake (Vinale *et al*., 2008), thereby cre-

Table 1. Growth and growth attributes of transplanted rice as influenced by seed treatment, seeding density and age of seedlings at transplanting (mean data of 2 years)

Treatment	Seedling mortality (%)	Plant height (cm)	Effective tillers (%)	Sterility (%)	Days to 50% flowering (days)	Days to maturity (days)	Panicle length (cm)
Seed treatment							
S_1	7.42	123.6	64.7	13.9	113.5	140.3	26.5
S_2	7.82	124.2	64.2	13.8	113.5	140.3	26.9
S_3	9.08	122.1	63.1	14.7	113.6	140.2	26.1
SEm±	0.29	0.4	0.2	0.3	0.5	0.3	0.1
CD (P=0.05)	1.15	1.4	0.7	NS	NS	NS	0.2
Seeding density							
D_1	7.53	123.4	63.9	14.2	113.2	140.4	26.5
D_2	8.63	123.1	63.8	14.1	114.1	140.2	26.5
D_3	8.15	123.4	64.2	14.1	113.3	140.2	26.3
SEm±	0.37	0.3	0.2	0.2	0.3	0.2	0.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.2
Age of seedlings at transplanting							
A_1	11.29	118.5	62.4	15.8	117.2	146.4	26.1
A_2	4.92	128.1	65.6	12.5	109.8	134.1	26.9
SEm±	0.30	0.2	0.1	0.2	0.3	0.2	0.1
CD (P=0.05)	1.05	0.5	0.4	0.5	0.7	0.7	0.2

S_1, Pseudomonas @ 10 g/1 kg of seed; S_2, Trcichoderma @ 10 g/1 kg of seed and S_3, no seed treatment; D_1, 40 g/m2, D_2, 50 g/m2 and D_3, 60 g/m2; A_1, 42 days old seedlings and A_2, 21 days old seedling ating a favourable microenvironment for seed germination and seedling establishment.

Weed density

Seed treatment with bio-control agents and seedlings grown at different seeding densities did not influence the weed density at 20 DAT (data not given). However, the plots planted with 21 days young seedlings recorded a lower density of dominant weeds *Cyperus difformis, Echinochloacolona, and Lwidigia octovalvis* and total weed density (68.5 weeds / m^2) as compared to transplanting of 42 days old seedlings (78.9 weeds / m^2). Adequate crop establishment and early vigour of seedlings after transplanting compete with the emerging weeds in rice fields thus reducing the crop weed competition. Under favourable soil moisture, young seedlings have high root development, high growth rate, rapid production of tillers, and cover the soil quickly with canopy which ultimately suppresses the weed growth in the main field (EI-Ghandor and Khozimy, 2019).

Growth and growth attributes

The growth and growth attributes of transplanted rice as influenced by seed treatment, seeding density and age of seedlings at transplanting are presented in Table 1. Seed treatment with *Trichoderma* formulation recorded significantly ($p<0.05$) higher plant height (124.2 cm) as compared to control (122.1 cm). Application of bio-agents increases root length, and dry weight of shoots and roots, which is reflected in increased plant height and better plant development after transplanting. Young seedlings registered higher ($p<0.05$) plant height in transplanted rice which is also supported by the findings of Pandey *et al*. (2021). Transplanting of young seedlings registered a significantly higher number of tillers per unit area. Seedling age affects both shoot and root character and young seedlings produce a greater number of tillers per unit area (Pandey *et al*., 2021). Days to 50% flowering and days to maturity were not influenced by seed treatment with bio-control agents and sowing density at rice nurseries. Whereas, young seedlings overcame the transplanting shock comparatively in a shorter period and established the crop quickly as compared to the old seedlings. A young seedling reduces the whole growth phase as compared to old seedlings (Aggarwal and Singh, 2015). Total crop growth from sowing to maturity was prolonged by an average of 12 days due to the transplanting of 42 old seedlings. Lampayan *et al*. (2019) have also reported an increase in crop duration due to delays in transplanting of rice. Delay in transplanting significantly affected the number of filled grains per panicle. Transplanting of 42-day seedlings resulted in higher sterility (15.8%) as compared to the young seedlings.

Yield and yield attributes

The yield, yield attributes and economics of transplanted rice, as influenced by seed treatment, seeding density and age of seedlings at transplanting, are presented in Table 2. Seed treatment with *Trichoderma* formulation significantly ($p<0.05$) increased the grain and straw yield of transplanted rice by 14.0% and 12.3%, respectively, over the control. The increase in yield was due to a higher number of panicles, number of grains per panicle and 1000-grain weight. Several authors have reported enhancement in rice grain yield due to the treatment with bio-control agents. The seeding density of 50 g/m2 exhibited higher ($p<0.05$) grain yield compared to the seeding density of 60 g/m2. However, the grain yield of 50 and 40 g/m2 seeding density was statistically at par. Lower seeding density produces healthy seedlings with high seedling vigour index (Sarangi *et al.,* 2015)*,* taller plants, more effective tillers and higher grain yield (Singh *et al*., 2018). Transplanting of 42-day-old seedlings of rice variety CR Dhan 314 resulted in a significant reduction in grain yield (10.1%) over the 21-day-old seedlings. The reduction in grain yield was attributed to a decreased number of panicles per unit area, fewer grains per panicle, and lower test weight. Young seedlings (21 days) increased the rice growth phase, ensuring a better plant population and higher dry mass accumulation which resulted in higher grain and straw yield. Delay in transplanting causes a reduction in number of effective tillers per hill, grains per panicle, sink capacity per tiller and grain yield (Liu *et al.,* 2017). The Harvest index of transplanted rice was not affected due to seed treatments and different seeding densities (Table 2). In contrast, young seedlings enhance the harvest index by better partitioning photosynthates to grains compared to older seedlings.

Land productivity

More production per unit of land and time is one of the criteria for sustainable crop production. Seed bio-priming with *Trichoderma* formulation significantly increased grain yield without affecting crop duration which ultimately recorded higher land productivity (Table 3). As seeding density influences the grain yield thus lower seeding density recorded higher land productivity. Transplanting of 21-day-old seedlings also registered higher land productivity (45.6 kg/ha/day) compared to 42-day-old seedlings. Transplanting of 42-day-old seedlings caused a reduction in land productivity by 17.8% due to an increase in crop duration and a decrease in yield.

Economics

A technology should be economically viable so that it

Table 2. Yield, yield attributes and economics of transplanted rice as influenced by seed treatment, seeding density and age of seedlings at transplanting (mean data of 2 years)

Treatment	Panicles/ m^2	Grains/ Panicle	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	HI	Gross return ($\times 10^3$ ₹/ha)	Net return ($\times 10^3$ ₹/ha)	Benefit: cost ratio	Cost of production (₹/kg)
Seed treatment										
S_1	249.4	144.8	30.86	5.97	6.76	46.96	120.9	61.7	2.04	9.91
S_2	250.7	147.8	30.97	6.11	6.85	47.08	123.2	64.1	2.08	9.72
S_3	238.2	138.7	30.40	5.36	6.10	46.71	108.0	48.8	1.83	11.1
SEm±	0.71	0.61	0.07	0.02	0.04	0.17	0.4	0.4	0.01	0.03
CD (P=0.05)	2.8	2.4	0.26	0.08	0.14	NS	1.6	1.6	0.03	0.14
Seeding density										
D_1	247.7	144.5	30.88	5.87	6.63	47.01	118.8	59.6	2.01	10.11
D_2	247.3	146.2	30.71	5.91	6.66	46.98	119.2	60.0	2.01	10.08
D_3	243.2	140.7	30.64	5.66	6.43	46.76	114.1	55.0	1.93	10.54
SEm±	0.72	0.80	0.10	0.05	0.04	0.11	1.0	1.0	0.02	0.03
CD (P=0.05)	2.2	2.5	NS	0.16	0.13	NS	3.1	3.1	0.05	0.28
Age of seedlings at transplanting										
A_1	236.5	138.5	30.45	5.50	6.37	46.31	111.0	55.9	1.88	10.81
A_2	255.6	149.0	31.03	6.12	6.77	47.53	123.7	64.5	2.09	9.68
SEm±	0.71	0.53	0.07	0.04	0.04	0.10	0.7	0.7	0.01	0.06
CD (P=0.05)	2.1	1.6	0.20	0.11	0.12	0.30	2.1	2.1	0.04	0.19

S_1, Pseudomonas @ 10 g/1 kg of seed; S_2, Trichoderma @ 10 g/1 kg of seed and S_3, no seed treatment; D_1, 40 g/m2, D_2, 50 g/m2 and D_3, 60 g/m2; A_1, 42 days old seedlings and A_2, 21 days old seedling

can be easily adopted in the farmer's field. The use of *Trichoderma* formulation as seed treatment recorded a 14.1% increase in gross return over control (Table 2). The increase in gross return was due to higher grain and straw yield as compared to no seed treatment. Among the seeding density at the nursery, 50 g/m² registered a 4.4% higher gross return as compared to higher seeding density (60 g/m²) but it was equivalent to 40 g/m². Transplanting of young seedlings (21 days) significantly reported higher gross return 123.7×10^3/ha and B: C ratio (2.09) as compared to 42-day-old seedlings. The use of young seedlings reduced the cost of production by 10.5% as compared to 42-day-old seedlings. The reduced cost of production was due to higher yield achieved under young seedlings while maintaining the same cultivation cost.

Water productivity

In the current scenario, where natural resources like water are scarce, the intervention of technologies should focus not only on increasing yield but also on improving water productivity. Seed priming with *Trichoderma* formulation significantly ($p<0.05$) resulted in an increase in physical and economical water productivity over control (Table 3). Young seedlings registered 12.5 and 12.4% higher physical and economic water productivity, respectively, compared to 42-day-old seedlings. Old seedlings prolonged the crop duration and thus consumed more water for crop growth and development, but produced less grain yield which ultimately reflected in the reduction in physical and economical water productivity.

In conclusion, this study underscores the efficacy of specific management practices in enhancing the yield of transplanted rice in shallow lowland conditions. Treating seeds with Trichoderma (NRRI formulation) at 10 g/kg was identified as the most effective seed treatment. Additionally, a seeding density of 40-50 g/m² in the nursery and transplanting 21-day-old seedlings were optimal for achieving high yields. These practices are rec-

Table 3. Effect of seed treatment, seedling density and age of seedlings on land and water productivity (mean data of 2 years)

Treatment	Land productivity (kg/ha/day)	Physical water productivity (kg/m^3)	Economic water productivity (₹/m^3)
Seed treatment			
S_1	42.7	0.725	14.68
S_2	43.7	0.743	14.97
S_3	38.3	0.651	13.13
SEm±	0.2	0.050	0.05
CD (P=0.05)	0.6	0.010	0.19
Seeding density			
D_1	41.9	0.712	14.41
D_2	42.3	0.719	14.49
D_3	40.5	0.688	13.89
SEm±	0.35	0.010	0.12
CD (P=0.05)	1.1	0.019	0.38
Age of seedlings at transplanting			
A_1	37.5	0.665	13.43
A_2	45.6	0.748	15.09
SEm±	0.3	0.010	0.10
CD (P=0.05)	0.8	0.013	0.26

S_1, *Pseudomonas* @ 10 g/1 kg of seed; S_2, *Trcichoderma* @ 10 g/1 kg of seed and S_3, no seed treatment; D_1, 40 g/m^2, D_2, 50 g/m^2 and D_3, 60 g/m^2; A_1, 42 days old seedlings and A_2, 21 days old seedling

ommended for farmers seeking to maximize the productivity of rice in these specific agro-ecological conditions.

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