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Research Paper

Crop performance, nutrient uptake vis-a-vis weed suppressive ability of mechanically transplanted rice (*Oryza sativa*) as influenced by age of seedlings and planting density

NAVNEET AGGARWAL[1] AND AVTAR SINGH[2]

Punjab Agricultural University, Ludhiana, Punjab 141 004

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ABSTRACT

An experiment was conducted during the rainy season of 2010 and 2011 at Punjab Agricultural University, Ludhiana to investigate the effect of seedling age and planting densities on crop performance and weed-suppressive ability of mechanically transplanted rice (*Oryza sativa* L.). The experiment comprising seedlings of 3, 4 and 5 weeks age and planting densities of 30 cm × 12 cm, 30 cm × 14 cm and 30 cm × 16 cm, was conducted in a factorial randomized block design with 4 replications. Mechanical transplanting of 3 weeks old seedlings showed superiority in terms of plant height, dry-matter accumulation and number of tillers to 4 and 5 weeks old seedlings when recorded at different growth stages. Transplanting of 3 and 4 weeks old seedlings were equally effective in their weed suppressive ability and certainly better than 5 weeks old seedlings, as dry-weight of weeds was significantly lesser than that in 5 weeks old seedlings. Leaf area-index (LAI) and photosynthetically active radiation (PAR) interception recorded at panicle-emergence stage, which were statistically at par in 3 and 4 weeks old seedlings but significantly higher than that in 5 weeks old seedlings. Mechanical transplanting of 3 and 4 weeks old seedlings recorded significantly higher N, P and K uptake than that in 5 weeks old ones. The planting density of 30 cm × 12 cm recorded significantly higher LAI, PAR interception, yield-attributing characters, grain yield and N, P and K uptake than that in 30 cm × 14 cm and 30 cm × 16 cm. Planting density of 30 cm × 12 cm proved to be optimum spacing for mechanically transplanted rice, as it gave 4.7 and 12.2% higher grain yield over the 30 cm × 14 cm and 30 cm × 16 cm spacing respectively. It also proved to be significantly better for weed-suppressive ability, as it recorded reduction in dry-matter of weeds to the tune of 8.6–26.5% and 17.1–37.3% over 30 cm × 14 cm and 30 cm × 16 cm respectively, at different growth stages.

Key words **:** Mechanically transplanted rice, NPK uptake, PAR, Planting density, Seedling age, Weed suppressive ability

The mechanical transplanting of rice is gaining interest because of shortage of labour for timely completion of manual transplanting. Mechanical transplanting proved beneficial in saving of 66% cost of transplanting and required only 7% of time for transplanting as compared with manual transplanting (Sharma *et al*., 2002). Moreover, it is seen that population of the plants in the farmers field is generally low (18–20 plants/m^2) because the hired labour tend to transplant more area in limited time for their higher earnings but it results in reduced grain yields. This problem can be tackled with mechanical transplanting of rice as it helps to transplant the desired number of plants/m^2 in short span of time.

Seedling age has a tremendous influence on plant height, tiller production, panicle length, grain formation and other grain yield-contributing parameters and yield of rice (Ginigaddara and Ranamukhaarachchi, 2011). If the seedling age is more than optimum, then less tillers are produced due to reduced vegetative phase thereby results in poor yield (Mobasser *et al*., 2007). It also affects the competitive ability of crop against the weeds. Planting density is another important factor which influences crop performance as narrow row spacing improves a crop’s competitiveness with weeds by developing faster canopy cover and allowing less light penetration through its leaves (Chauhan and Johnson, 2011). The optimum seedling age and planting density varies with the method of rice establishment, viz. manual transplanting, system of rice intensification etc. Delaulanie (2011) found very young seed-

[1]**Corresponding author Email:** navneetpulsespau@yahoo.com
[1]Assistant Agronomist, Department of Plant Breeding and Genetics, [2]Senior Agronomist, Punjab Agricultural University, Ludhiana, Punjab 141 004

lings (around 14 days) to be promising in the system of rice intensification (SRI) and transplanting 28 days old seedlings recorded higher mortality rate over 14 days old seedlings (Kewat *et al.,* 2002). Similarly, in SRI, Singh *et al* (2013) reported that seedlings planted at wider spacing of 30 cm × 30 cm proved significantly better than that in closer plant spacings of 25 cm × 25 cm. However, optimum planting density for manually transplanted rice is 33 plants/m^2 (Dhaliwal and Kular, 2014). But information on such studies is very limited under mechanically transplanted rice.

Weeds are one of the major biological constraints to rice production. Development of cultural weed-management strategies is very crucial to maintain or increase the sustainability of rice production. As competition for light is an important factor in crop–weed interference, the use of weed–competitive cultivars, narrow row spacing and high seeding rates are some of the key strategies that triggers closing the canopy quickly thereby help in suppressing weeds by increasing shade on the weeds. However, designing such strategies in mechanically transplanted rice requires an understanding of the differential responses of age of seedlings and planting densities for rice productivity and weed growth. But very little literature is available which describes effect of age of seedlings and planting density on the yield of mechanically transplanted rice and its suppressive ability on associated weeds. Therefore the primary aim of making of this study was to showcase the production potential of mechanically transplanted rice and its competitiveness against associated weeds in pursuit to develop sustainable, eco-friendly and labour-saving technologies of rice production.

MATERIALS AND METHODS

A field experiment was conducted in the rainy season (*kharif*) 2010 and 2011 at Punjab Agricultural University, Ludhiana (30°56'N, 75°52'E; 247 m above sea-level) to study the weed-suppressive ability, performance of mechanically transplanted rice, nutrient uptake by crop as affected by age of seedlings and planting density. The experiment was conducted in a factorial randomized complete-block design with 9 treatments formed by the combinations of 3 age of seedlings, viz. 3, 4 and 5 weeks old and 3 planting densities, i.e. 30 cm × 12 cm, 30 cm × 14 cm and 30 cm × 16 cm and the treatments were replicated 4 times. The soil was a deep alluvial loamy sand, Typic Ustochrept, medium in organic carbon (4.3 g C/kg at 0–15 cm), $KMnO_4$-oxidizable N (341 kg/ha), Olsen-P (18.5 kg/ha) and 1 N NH_4OAc-extractable K (230 kg/ha), normal soil reaction (pH 8.0) and electrical conductivity (0.21 dS/m). The total rainfall of 652 mm and 1,190 mm was received during 2010 and 2011 respectively.

The sowing of mat-type nursery was done on 13, 20 and 27 May in 2010 and on 16, 23 and 30 May in 2011 to have seedlings of age 3, 4 and 5 weeks old, respectively at the time of transplanting. For raising the mat-type nursery of rice cv. 'PR 115', the field was properly leveled and was made free of weeds. Plastic trays of dimensions 58 cm × 28 cm × 2 cm filled with properly sieved soil were placed on the perforated polythene sheet of 50–60 gauge. About 100 g of pre-germinated seeds of rice were uniformly spread in each tray. The seeds were then covered with very thin layer of soil and water was sprinkled with hand sprayer for proper setting of the soil and seeds. After sowing, the nursery bed was irrigated twice a day with mild flow of water. Urea was applied @ 300 g for 200 mats at an interval of 10 days after sowing.

The mechanical transplanting of seedlings of rice was done under puddled conditions on 17 June and 19 June in 2010 and 2011 respectively, with Japanese transplanter,

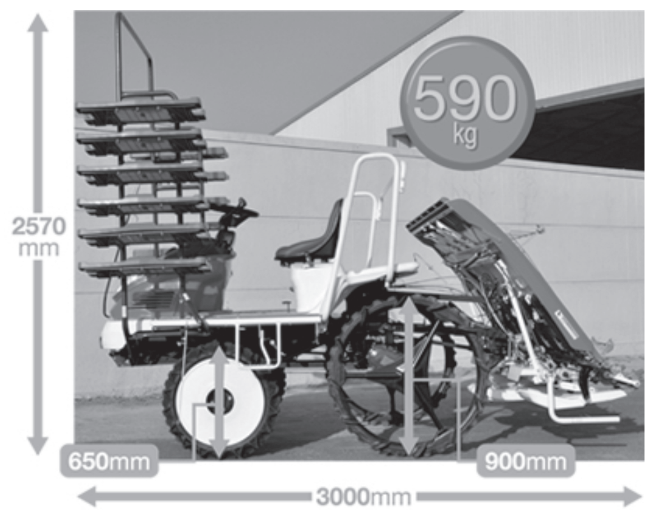


Fig. 1. Specifications of Japanese mechanical transplanter used.

Fig. 2. Mechanical transplanting in progress.

Model: NSPU- 68 C (Figs. 1 and 2). The 3, 4 and 5 weeks old seedlings were transplanted mechanically at spacing of 30 cm × 12 cm, 30 cm × 14 cm and 30 cm × 16 cm as per the treatments. For changing the plant-to-plant spacing, a simple hand-driven liver attachment provided in the machine was used. Sufficient water level for washing of front fingers of mechanical transplanter was maintained in the field. The crop was fertilized with 125, 13 and 25 kg of N, P and K/ha respectively. One-third of N and full dose of P and K was applied before the last puddling and remaining N was top-dressed in 3 equal splits after 1, 3 and 6 weeks from the date of transplanting. Urea, single superphosphate and muriate of potash were used as source of nutrients. Ferrous sulphate (1%) was applied through foliar application on 8 July and 11 July in 2010 and 2011 respectively. For the proper establishment of the seedlings, water was kept standing continuously for the first 2 weeks after transplanting. Afterwards, the plots were irrigated 2 days after drainage of applied irrigation water. The depth of each irrigation was 75 mm. The plant-protection measures were adopted as per the standard recommendations. The crop was harvested manually 15-cm above-ground level during the first fortnight of October in both the years.

Periodic observations on dry-matter accumulation were recorded 30, 60, 90, days after transplanting (DAT) and at harvest stage of the crop by cutting the plants from 50-cm-row length from the base, dried in the sun for some period and then dried in the oven at 65^{o}C till constant dry weight was achieved and then converted in g/m^2. Leaf-area index was measured at panicle-emergence stage of crop with the help of Plant Canopy Analyzer (LI-COR) Model LAI-2000. Total number of tillers were counted at 30, 60, 90 DAT and at harvest stage from 3 fixed spots. Photosynthetically active radiation (PAR) interception was measured at panicle-emergence stage by using line quantum sensor (L1-COR Photometer model LI-191-84), which measures quantum (photon) response in the wavelength range of 400–700 nm. Nitrogen content in paddy grains and straw was determined with Kjeldahl's distillation method. The P content in grains and straw was determined by using vanado molybdo phosphoric yellow colour method in nitric acid system. Potassium content in paddy grains and straw was determined from the digested material used for the determination of P content with the help of flame photometer. The N, P and K contents (%) in grains and straw were multiplied with the grain yield and straw yield, respectively, to calculate the N, P, and K uptake by paddy grains and straw.

All the data were subjected to analysis of variance (ANOVA) as per the standard procedures. The comparison of treatment means was made by critical difference (CD) at P ≥ 0.05.

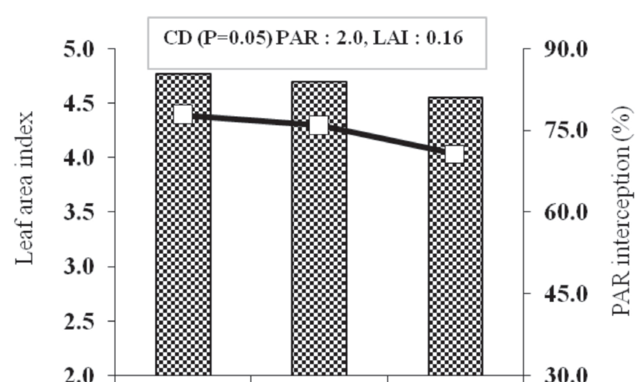
RESULTS AND DISCUSSION

Dry matter accumulation by crop

Transplanting of 3, 4 and 5 weeks old seedlings recorded statistically similar dry-matter accumulation at 30 DAT. At subsequent growth stages, i.e. at 60, 90 DAT and at harvesting, 3 weeks old seedlings recorded significantly higher dry-matter accumulation over 4 and 5 weeks-old seedlings. Dry matter accumulation by crop was significantly increased with successive increase in planting density from 30 cm × 16 cm to 30 cm × 12 cm at all the crop-growth stages. At harvesting, 30 cm × 12 cm planting density resulted in 4.2 and 11.2% higher dry matter than 30 cm × 14 cm and 30 cm × 16 cm respectively. The increase in dry-matter production at higher planting densities may be ascribed to higher plant population per unit area and more number of tillers (Table 1).

Leaf area index and photosynthetically active radiation interception

Leaf area index (LAI) and photosynthetically active radiation (PAR) interception were significantly influenced by different age of seedlings (Fig. 3). The highest LAI and PAR interception were recorded in mechanical transplanting of 3 weeks old seedlings which was statistically at par with 4 weeks old seedlings but significantly higher than 5 weeks old seedlings. The results can be explained by the fact that since the young seedlings possess high root activity and high photosynthetic activity that cause increase of leaf area and dry-matter yield more than older one and hence resulted in higher PAR interception. Further, LAI and PAR interception increased significantly with the successive increase in the planting density from 30 cm × 16 cm to 30 cm × 12 cm (Fig. 4). The increase in LAI and PAR interception with increase in planting density may be



	3 weeks-old	4 weeks-old	5 weeks-old
PAR	85.4	84.0	81.0
LAI	4.39	4.30	4.04

Fig. 3. Leaf-area index and photosynthetically active radiation interception as influenced by seedling age recorded at panicle-initiation stage.

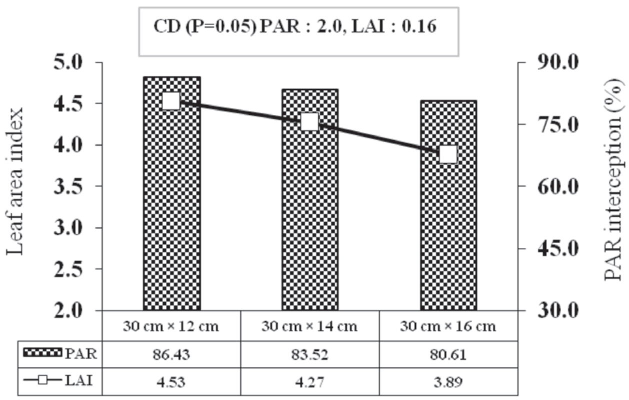


Fig. 4. Leaf-area index and photosynthetically active radiation interception as influenced by planting density recorded at panicle initiation stage.

attributed to increase in dry-matter production and tillers/m^2 (Table 1).

Yield attributes, yield and economics

Number of tillers is an important parameter which plays vital role in weed suppression and competition for space, moisture and sunlight. Total number of tillers (Table 1) at 30, 60, 90 days and at harvesting revealed that maximum tillers/m^2 were recorded at 60 days in all the treatments. Thereafter, number of tillers was declined that might be due to the mortality of the tillers which were produced at the later stages of crop growth. The number of tillers was statistically similar under all the age of seedlings when recorded at different stages of crop growth, although 3 weeks old seedlings had a numeric edge on 4 and 5 weeks old seedlings. Kewat *et al.* (2002) also reported that transplanting of 21 and 28 day old seedlings produced statistically similar number of tillers/unit area. The effect of planting density on the number of tillers/m^2 was found to be significant at all the stages of crop growth. At 30 days, planting density of 30 cm × 12 cm resulted in significantly higher number of tillers/m^2 than 30 cm × 14 cm and 30 cm × 16 cm. At 60, 90 days and at harvesting, planting density of 30 cm × 12 cm recorded significantly higher number of tillers than 30 cm × 14 cm and 30 cm × 16 cm, but planting densities of 30 cm × 14 cm and 30 cm × 16 cm were at par with each other. At harvesting, planting density of 30 cm × 12 cm produced 4.6 and 6.5% more tillers than planting density of 30 cm × 14 cm and 30 cm × 16 cm respectively. More plant population per unit area at closer planting density of 30 cm × 12 cm may have resulted in more tillers/m^2 than that in the wider planting densities.

Panicle weight is directly related to the grain yield of rice. The age of seedlings had non-significant effects on the panicle weight. However, different planting densities resulted in significant differences in the panicle weight. The highest panicle weight was recorded in the planting density of 30 cm × 16 cm, being statistically at par with 30 cm × 14 cm was significantly higher than 30 cm × 12 cm. This might be due to the better growth of the plants on account of more available space in planting density of 30 cm × 16 cm than 30 cm × 12 cm and 30 cm × 14 cm. These results confirm the findings of Ghosh (2000).

Mechanical transplanting of 3 weeks old seedlings gave significantly better biological yield than that obtained with 4 and 5 weeks old seedlings (Table 1). Mechanical transplanting at 30 cm × 12 cm spacing recorded the highest biological yield and it was significantly higher than that obtained with wider planting densities of 30 cm × 14 cm and 30 cm × 16 cm. These results are in line with the find-

Table 1. Periodic dry matter accumulation, tiller count, panicle weight and yield of mechanically transplanted rice as influenced by age of seedlings and planting densities (pooled data of 2 years)

Treatment	Dry matter accumulation (g/m^2)				Tillers/m^2				Panicle weight (g)	Biological yield (t/ha)	Grain yield (t/ha)	Net returns (×10^3 ₹/ha)
	30 DAT*	60 DAT	90 DAT	At harvesting	30 DAT	60 DAT	90 DAT	At harvesting				
Age of seedling												
3 weeks-old	183.3	599.0	1,204.7	1,586.5	331.3	453.4	435.3	431.1	3.05	15.87	7.16	59.1
4 weeks-old	177.5	575.5	1,162.1	1,519.4	319.6	446.6	432.7	426.9	3.08	15.19	7.18	59.4
5 weeks- old	185.7	545.8	1,119.1	1,442.2	317.6	441.4	427.1	420.5	3.11	14.42	7.09	58.3
SEm±	2.5	6.2	12.2	13.2	4.9	3.6	3.5	3.5	0.05	0.13	0.12	1.7
CD (P=0.05)	NS	17.6	34.6	37.4	NS	NS	NS	NS	NS	0.37	NS	NS
Planting density												
30 cm × 12 cm	197.2	605.2	1,224.8	1,590.4	341.9	461.8	446.0	441.6	2.80	15.90	7.53	63.2
30 cm × 14 cm	182.3	573.0	1,167.6	1,526.3	325.4	443.7	428.6	422.2	3.16	15.26	7.19	59.5
30 cm × 16 cm	167.0	542.0	1,093.6	1,431.6	301.2	435.9	420.5	414.8	3.27	14.32	6.71	54.2
SEm±	2.5	6.2	12.2	13.2	4.9	3.6	3.5	3.5	0.05	0.13	0.12	1.7
CD (P=0.05)	7.1	17.6	34.6	37.4	16.1	10.3	9.9	10.0	0.16	0.37	0.33	4.3

*DAT, Days after transplanting

ings of Bozorgi *et al.* (2011). The grain yield was statistically at par at different age of seedlings (Table 1). These findings are in conformity with those of Faghani *et al.* (2011), who reported that the seedling age had non-significant effect on grain yield. Further, planting density of 30 cm × 12 cm recorded significantly higher grain yield than 30 cm × 14 cm and 30 cm × 16 cm. The magnitude of increase in grain yield of 30 cm × 12 cm was 4.7 and 12.2% over the 30 cm × 14 cm and 30 cm × 16 cm respectively. The higher grain yield with closer planting density might be owing to significantly higher number of tillers, a major yield-contributing character than in the wider planting densities (Table 1). The interaction effect of age of seedlings and planting density on biological yield and grain yield of rice was found to be non-significant.

The results showed that mechanical transplanting of 3, 4 and 5 weeks old seedlings had non-significant effect on net returns (Table 1). Different planting densities had significant influence on the economics of mechanically transplanted rice. It was observed that planting density of 30 cm × 12 cm gave statistically similar net returns as that in 30 cm × 14 cm but significantly higher than in 30 cm × 16 cm. Further, Aggarwal (2013) reported that mechanical transplanting of 'PR 115' rice under similar conditions in Punjab resulted in 94.6% saving in time for transplanting and reduced the cost of transplanting by 75.9% compared with the manual transplanting. Similarly, Gill and Walia (2013) also reported that machine-transplanted basmati rice proved more remunerative than conventional manually transplanted rice under similar experimental conditions.

Weed population and dry weight

Weed-population determines the magnitude of crop weed competition. The major weed flora of the experimental field was comprised of *Cyperus iria*, *Cyperus rotundus*, *Echinochloa colonum*, *Echinochloa crusgalli* and *Eclipta alba*. The data recorded on weed population as influenced by different age of seedlings and planting densities (Table 2) revealed that transplanting of 3, 4 and 5 weeks old seedlings recorded statistically similar weed population at 30 and 60 days. Population of different weed species tended to decrease with increasing planting densities when recorded at different growth stages (Table 2). This might be attributed to the suppression effect of crop on weeds in the denser crop canopies.

The dry weight of weeds recorded at 30, 60, 90 days and at harvesting was significantly influenced by different age of seedlings (Table 2). Mechanical transplanting of 3 weeks old seedlings recorded the lowest dry weight of weeds, which was statistically at par with that in 4 weeks old seedlings but significantly lower than that in 5 weeks old seedlings. Further, dry weight of weeds was reduced significantly with increasing planting density from 30 cm × 16 cm to 30 cm × 12 cm at all the stages of crop growth. Closer crop canopy in 30 cm × 12 cm might resulted in better suppression of the weeds than wider spacing of 30 cm × 14 cm and 30 cm × 16 cm owing to higher LAI and more PAR interception (Fig. 4) and consequently reduced dry-matter accumulation by weeds.

Nutrient uptake by crop

Mechanical transplanting of 3 weeks old seedlings recorded the highest N, P and K uptake by grains which was statistically at par with 4 weeks old seedlings but significantly higher than 5 weeks old seedlings (Table 3). However, 3 weeks old seedlings recorded significantly higher N, P and K uptake by straw than both 4 and 5 weeks old

Table 2. Periodic dry matter of weeds as influenced by age of seedlings and planting densities (pooled data of 2 years)

Treatment	Weed population (numbers/m^2)		Dry-matter of weeds (g/m^2)			
	30 DAT	60 DAT	30 DAT	60 DAT	90 DAT	At harvest
Age of seedling						
3 weeks-old	3.48 (11.09)*	4.43 (18.62)	10.7	18.1	24.4	28.9
4 weeks-old	3.64 (12.24)	4.64 (20.49)	11.7	18.7	25.4	29.2
5 weeks-old	3.66 (12.37)	4.70 (21.08)	12.1	19.2	26.2	29.6
SEm±	0.11	0.13	0.3	0.4	0.5	0.3
CD (P = 0.05)	NS	NS	1.1	1.0	1.4	0.7
Planting density						
30 cm × 12 cm	3.01 (8.09)	4.03 (15.26)	9.9	17.0	19.6	22.2
30 cm × 14 cm	3.42 (10.67)	4.52 (19.46)	11.5	18.6	26.3	30.2
30 cm × 16 cm	3.88 (14.02)	5.21 (26.14)	13.0	20.5	30.1	35.4
SEm±	0.11	0.13	0.3	0.4	0.5	0.3
CD (P = 0.05)	0.28	0.32	1.1	1.0	1.4	0.7

*Data subjected to square-root transformation. Figures in parentheses are means of original values

Table 3. Nutrient uptake by crop as influenced by age of seedlings and planting densities (pooled data of 2 years)

Treatment	Nutrient uptake by grains (kg/ha)			Nutrient uptake by straw (kg/ha)		
	N	P	K	N	P	K
Age of seedling						
3 weeks-old	91.6	19.0	25.3	56.4	19.4	152.2
4 weeks-old	88.0	18.1	23.5	50.5	16.7	137.0
5 weeks-old	83.9	16.4	21.8	44.7	15.3	122.2
SEm±	1.5	0.4	0.5	0.6	0.3	1.5
CD (P = 0.05)	4.2	1.2	1.9	1.6	0.8	4.3
Planting density						
30 cm × 12 cm	95.7	19.9	26.3	55.1	19.7	151.0
30 cm × 14 cm	87.9	17.8	23.6	50.5	16.7	136.7
30 cm × 16 cm	79.9	15.8	20.6	46.1	15.0	123.7
SEm±	1.5	0.4	0.5	0.6	0.3	1.5
CD (P = 0.05)	4.2	1.2	1.9	1.6	0.8	4.3

seedlings. Further, planting density of 30 cm × 12 cm resulted in highest N, P and K uptake by grains and straw, which was significantly higher than wider planting densities of 30 cm × 14 cm and 30 cm × 16 cm. These results are in line with the findings of Ram *et al.* (2014) who reported that planting density of 25 cm × 25 cm recorded significantly higher NPK uptake by crop as compared to wider planting density of 30 cm × 30 cm.

It was concluded that 3, 4 and 5 weeks old seedlings can be transplanted mechanically at planting density of 30 cm × 12 cm for enhancing rice yields, higher NPK uptake and better suppression of associated weeds. Further, mechanical transplanting is a promising solution to avoid yield reduction, as it helps in avoiding delay in transplanting under labour-scarce conditions particularly in Indo-Gangetic plains.

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