



Development and evaluation of tractor operated transplanter for wash root paddy (*Oryza sativa*) nursery

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Received: 06 April 2022; Accepted: 01 December 2025

ABSTRACT

Most of the paddy (*Oryza sativa* L.) crop is typically transplanted manually by migrant workers in north-western Indian region. Despite several efforts to promote the existing mat-type nursery-fed paddy transplanter, farmers have not adopted this technology as well as NAREGA act of Government of India impedes the migrant workers movement to the region and creates labour crises during peak transplanting season. Therefore, there is a need of transplanter for wash root nursery. The study was carried out during rainy (*kharif*) season of 2020 and 2021 at Punjab Agricultural University, Ludhiana, Punjab to develop and evaluate paddy transplanter for wash root nursery under field conditions. Age of nursery was selected as independent parameters whereas the hill to hill spacing missing index, multiple index, field capacity, damage percentage, yield, fuel consumption and cost of operation were observed. The age of nursery has significant effect on missing index, multiple index, damage percentage, field capacity and cost of operation whereas, hill to hill spacing, planting efficiency, fuel consumption and yield has non-significant effect. Thirty-five days of nursery was found optimum for the developed paddy transplanter under field evaluation at fixed forward and mechanism speed. At this combination, the mean hill to hill spacing, missing index, multiple index, field capacity, damage percentage, planting efficiency, yield, fuel consumption and cost of operation were 142.5 mm, 31.18%, 4.40%, 0.29 ha/h, 4.44%, 60.75%, 4.75 t/ha, 4.13 L/h and 10,136.25 ₹/ha, respectively. The developed transplanter could results in increasing the mechanisation index in transplanting/sowing operation which is lowest as compared to other field crops.

Keywords: Mechanisation, Paddy, Rice, Transplanter, Wash root nursery

Asian farmers produced nearly 89.6% of the global paddy (*Oryza sativa* L.) production, with China and India attributing nearly 51.85% of total rice crop production (Singh *et al.* 2023). In India, it accounts for approximately 34.5% of total area under food grain and accounting for more than 40.0% of total food grain production during 2022 (MA&FW 2025).

The mechanisation index in transplanting was recorded lowest in comparison to other operations of paddy cultivation (Mehta *et al.* 2019). In paddy transplanting, a nursery of nearly 3–4 weeks old is transplanted in the puddled field either manually or with the assistance of a mechanical transplanter (mat type nursery) (Dixit *et al.* 2007). Manual transplanting is a time-consuming, expensive, and labour-intensive process that accounts for roughly half of total

paddy production costs (Chaudhary *et al.* 2005). Suboptimal spacing during manual transplanting leads to low plant density and yields (Alipour and Mobasser 2021). Therefore, optimising yield requires timely transplanting, which is more achievable by reducing dependence on agricultural labour (Pandey *et al.* 2001). A mechanical paddy transplanter, on the other hand, is particularly advantageous because it can reduce peak labour demand during transplanting operations. Mechanical transplanting is a promising method that saves labour, reduces effort, ensures timely and optimal planting, and increases productivity (Yogeswari and Porpavai 2018).

The nurseries grown for paddy transplanting are of two types, wash root nursery (widely used by farmers) and mat type nursery. The wash root type nursery is usually raised by broadcasting pre-germinated seeds on the well-prepared seed bed. Once the seedlings reaches about 2 cm height, than the nursery flooded to a shallow layer of water. As soon as the seedlings gets 20–30 days old, seedlings were uprooted by manual labours and excess mud get washed with water (Anonymous 2009). For mat-type nurseries, place a mild steel (MS) frame on a perforated polythene sheet on level ground and fill it with a 4:2:1 mixture of soil, sand, and

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farmyard manure up to 15 mm. Pre-germinated seeds were evenly distributed in each frame at the recommended rate, covered with a thin soil layer, and lightly watered for proper soil setting. A plastic sheet was used to mulch the seedbed and protect seeds from birds until germination. Irrigation was done daily with a watering can for one week, then by flooding the bed (Dixit 2010).

Labour shortages have been a major issue in Punjab, particularly, during paddy transplanting and crop harvesting/threshing (Dixit *et al.* 2007). Majority of the paddy crop in the region is typically transplanted manually by migrant workers from the Indian states of Uttar Pradesh, Bihar, Chhattisgarh, and Odisha. The region's migrant labour influx has decreased during the last three years for a variety of reasons (Manes *et al.* 2013). Infrastructure initiatives in various parts of the country have offered workers of those states with alternate work opportunities. Additionally, the National Rural Work Guarantee Act (NREGA) of the national government also promises 100–150 days of employment opportunity at their native place (NREGA 2008). This provided the migrant workers the choice of working in their home state for livelihood. In the region, farmers have not adopted the existing mat type nursery feed paddy transplanter, despite several efforts to promote its use since the 1980s. This is due to various factors connected to the process of raising mat type nurseries (Chaba 2014). The commercially available mechanical transplanters in India are too expensive (Guru *et al.* 2018). Besides, the raising of this special mat type nursery necessitates skilled labour and continuous nutrition supply monitoring because mat type nursery is typically grown on poly-sheets or trays, which limits nutrition uptake from the ground. North-western India has a semi-arid climatic zone, resulting in generally high temperatures and dry conditions during the nursery period. As a result, mat type nurseries requires more attention and irrigation than wash root nurseries (Kumar *et al.* 2012). Yearly groundwater use surpasses the annual groundwater recharge in four regions: Punjab, Haryana, Rajasthan, and Delhi (Singla *et al.* 2022), where in Punjab and Haryana farmers use groundwater for irrigation. In between 2010–2019, there were six years (2011, 2012, 2014, 2015, 2016 and 2017) with deficient rainfall. During this time period, minimum rainfall had occurred in the year 2014 [50% of LPA (Long Period Average Rainfall)], followed by 2012 (54%), 2015 (69%), 2011 (72%), 2016 (75%) and 2017 (78%), respectively. Moreover, 2010 and 2019 experienced below LPA (7% less rain) than the average rainfall. The depletion of groundwater and decrease in rainfall during the monsoon season in north-western India worsens the situation (Singla *et al.* 2022). Due to these difficulties, farmers in the region have shown their willingness to implement new agricultural technologies (Pawar *et al.* 2017) whereas abandon existing mechanical transplanting techniques in favour of searching for a mechanical technology capable of transplanting wash root type nurseries. Hence, the objective of this study is to develop a paddy transplanter for wash root nursery and evaluate it under field conditions.

MATERIALS AND METHODS

Description of the developed paddy transplanter: A 9-row paddy transplanter comprising of main frame, gear boxes, chain-sprockets, major and sub-shafts, seedling trays and nine transplanting mechanisms was developed for transplanting wash root paddy nursery. The machine was operated by a tractor of 35 hp or more. A four-bar extended arm planting mechanism was employed to deliver seedling from seedling tray and place it into ground by the help of plunger which was operated via cam. The planting mechanism was powered by PTO (Power Take-off) through a series of gear boxes, chain-sprockets and connecting shafts (Fig. 1). Separate seedling box was provisioned to each planting mechanism on seedling tray. A pair of soil collectors also provided to main frame for removal of tyre tracks due to movement of tractor in puddled field and forming firm surface for transplanting (Fig. 2).

Experimental details: The evaluation of the developed transplanter was conducted during 2020 and 2021 at Punjab Agricultural University, Ludhiana (30.90° N, 75.81° E; at an elevation of 248 m amsl), Punjab. Seedlings (variety PR-126) of three different ages, viz. 25 days, 35 days, and 45 days were taken. Hill to hill spacing, missing index, multiple index, field capacity, damage percentage, planting efficiency, yield, fuel consumption, and cost of operation were selected as dependent parameters for field evaluation. The missing index indicates how frequently the desired spacing is not achieved during transplantation. It measures the percentage of spacing instances that exceed 1.5 times the

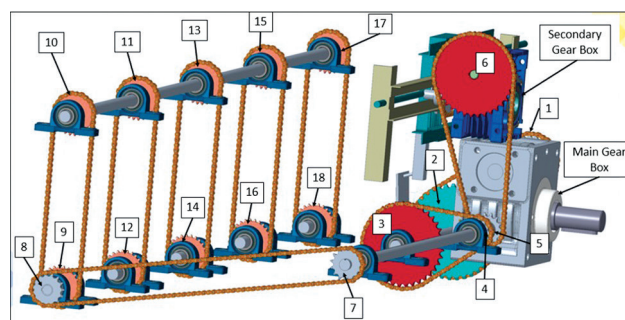


Fig. 1 Solid model of transmission system of developed paddy transplanter.

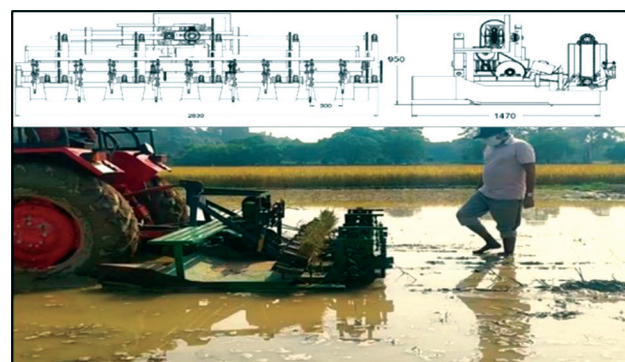


Fig. 2 Schematic and operational view of developed paddy transplanter.

theoretical spacing and is calculated according to equation (1) (Nare *et al.* 2014).

$$M_i = \frac{N_1}{n} \times 100 \quad (1)$$

Where N_1 , Count of instances where spacing in the region exceeds 1.5 times the theoretical spacing, as recorded within a m^2 sample area; n , Total number of hills in m^2 sample area

The multiple index (M_u) indicated the frequency of more than one hills planted within the desired spacing of 100 mm. It is represented by the percentage of spacing instances which are less than or equal to 0.5 times of the theoretical spacing. The multiple index (M_u) was calculated using equation (2) (Nare *et al.* 2014).

$$M_u = \frac{N_2}{n} \times 100 \quad (2)$$

Where N_2 , Count of hill spacings/ m^2 that are $\leq 0.5 \times$ theoretical spacing (100 mm); n , Total number of observations.

Seedling damage refers to the cutting or bending of seedlings resulted from physical pressure or force applied during transplantation by finger or plunger mechanisms. The percentage of damage was calculated using equation (3), as described by Patil *et al.* (2017).

$$D_s = \frac{(D_{cb})}{n_t} \times 100 \quad (3)$$

Where D_s , Damaged seedlings percentage; D_{cb} , Total number of damage seedlings observed due to cutting/bending; n_t , Total number of seedlings transplanted per run.

Hill to hill spacing serves as a degree of uniformity in seedling placement during transplantation, which is crucial for ensuring even growth and optimum resource utilisation. It is determined by calculating the average of hill-to-hill spacing values recorded within a one square meter sample area, following equation (4) as described by Patil *et al.* (2017).

$$H_s = \frac{\sum_{i=1}^n H_{si}}{n} \quad (4)$$

Where H_s , Hill to hill spacing; H_{si} , Hill to hill spacing at i^{th} term; n , Total number of spacing recorded.

Planting efficiency was evaluated by considering the instances where seedlings were absent at any planting point either due to the finger mechanism's failure to pick up seedlings or damage observed on seedlings by the transplanting mechanism. The calculation was performed according to equation (5) as described by Patil *et al.* (2017).

$$P_e, \% = 100 - M_i + M_u + D_s \quad (5)$$

Where M_i , Missing index; M_u , Multiple index; D_s , Damage percentage.

For determination of field capacity, the time consumed for turning, material handling, setup time of machine and total operation time were recorded. The fuel consumption

(L/h) was documented with the help of fuel gauge which was placed in between of the fuel line and recording done before and after of each replicated trial. The reading of fuel gauge was recorded before each replication and after the operation. The time taken was also recorded and fuel consumption was calculated by following equation (6):

$$\text{Fuel consumption} = \frac{G_e - G_i}{T_o} \quad (6)$$

Where G_e , Fuel gauge reading after operation (L); G_i , Initial fuel gauge reading (L); T_o , Time taken by the operation (h).

The costs associated with nursery raising and root washing for uprooted seedlings were held constant across each replication. The tractor was assigned a lifespan of 10 years, while the developed transplanter was given an expected service life of 8 years. Average annual use was defined by 140 h of operation for the developed transplanter. Operational costs were calculated according to BIS code IS 9164 (Zachariah 1979). The cost of nursery raising, uprooting, and washing was also considered in economics of developed paddy transplanter. The yield (t/ha) was measured from the sample collected by random one-meter square sample area. The sample was harvested, threshed manually, and weighed.

Method of statistical analysis: The numerical data collected during transplantation were analysed using the SAS OnDemand for Academics statistical software. Analysis of variance (ANOVA) following a randomised block design (RBD) was employed to assess the data. Statistical significance was determined at a probability level of $p < 0.05$; variations observed at $p \leq 0.05$ were regarded as significant. Tukey's post hoc test was subsequently applied to evaluate relationships both within and between groups.

RESULTS AND DISCUSSION

During operation of developed transplanter, different ages of nursery had significant effect on missing index, multiple index, damage percentage, field capacity and cost of operation whereas it has no significant effect on hill to hill spacing, planting efficiency, fuel consumption and yield (Table 1). Moreover, 25 and 35 days of nursery has shown no-significant difference on multiple index and damage percentage. Similar trend has been observed for 35 and 45 days of nursery for missing index and field capacity. Experiments showed that for each parameter, developed transplanter was found significantly different from control treatment.

Minimum missing index (33.11%), multiple index (2.22%), damage percentage (2.21%) and maximum planting efficiency (60.99%) for developed transplanter has been observed for 45 days of nursery. Additionally, the value of multiple index observed at 25 days and 45 days of nursery are identical (2.22%). Maximum field capacity (0.32 ha/h) and minimum cost of operation (₹9815.49/ha) for developed transplanter has been found for 25 days of nursery. Average hill to hill spacing has been observed as

139.47 mm. This is in affirmation to Anonymous (2021b) which stated that the acceptable range of hill to hill spacing was 100–150 mm. Maximum yield of 4.75 t/ha at 35 days of nursery and average fuel consumption of 4.18 L/h was recorded for developed transplanter. Moreover for control treatment, the observed value for different parameters were 18.00% (missing index), 3.67% (multiple index), 1.39% (damage percentage), 127.8 mm (hill to hill spacing), 80.61% (planting efficiency), 0.0047 ha/h (field capacity), ₹13,071/ha (cost of operation) and 5.99 t/ha (yield). Fig. 3 shows the trendlines followed by dependent parameters during experiment and the prediction equation of these trendlines are shown in Table 2.

The reason of higher missing index and low planting efficiency of developed transplanter in comparison to control treatment might be due to the non-uniform density of seedlings in the seedling tray, which lowered the picking mechanism's effectiveness. Furthermore, the reason of lower damage percentage at higher age of nursery may be due to the reason that at higher age, seedlings become more resilience against mechanical forces. The observed time of operation was almost same for all ages of nursery, the only difference in time was observed in refilling of seedling tray which might be the reason of variation in field capacity for developed transplanter. The higher multiple index in control treatment might be due to inconsistency of manual labour (Singh *et al.* 2023). Similarly, lower field capacity

and higher cost of operation observed in control treatment might be due to limitation of work by manual labour. Inconsistency was observed in control treatment due to manual labour resulting in failure to maintain desired hill to hill spacing, missing index and multiple index. Nevertheless, the refinement in segregation of seedlings in seedling box of developed transplanter may improve in maintaining the hill to hill spacing, reducing missing and multiple index which can lead to comparative grain yield. Higher field capacity and lower cost of operation is the biggest advantage of the developed transplanter which reduce the dependency of manual labour during peak season of paddy cultivation.

Numerical optimisation technique was used for prediction of optimum age of nursery for operation of developed transplanter. In order to optimise the operational parameters, it was necessary to minimise the missing index and fuel consumption while maximising planting efficiency and yield. Moreover, a range was selected for following parameters i.e. multiple index (<5%), damage percentage (<5%), hill to hill spacing (100–150 mm), field capacity (0.29–0.32 ha/h) and cost of operation (₹ 9,750–10,233/ha) during optimisation. It has been found that 35 days of nursery was optimum age of seedling with desirability of 0.507.

A tractor-operated paddy transplanter was developed based on design consideration and evaluated for various performance parameters to identify optimum operative conditions. The missing index, damage percentage, hill-

Table 1 Mean values of dependent parameters at different combination of age of nursery in field evaluation of developed tractor operated paddy transplanter

Treatment	Missing index (%)	Multiple index (%)	Damage percentage (%)	Hill to hill spacing (mm)	Planting efficiency (%)	Field capacity (ha/h)	Fuel consumption (L/h)	Cost of operation (₹/ha)	Yield (t/ha)
25 days	33.56 ^a	2.22 ^d	4.44 ^g	137.6 ^j	57.76 ^l	0.32 ⁿ	4.20 ^q	9,815.49 ^s	3.99 ^v
35 days	31.18 ^b	4.44 ^e	4.44 ^g	142.5 ^j	60.75 ^l	0.29 ^o	4.13 ^q	10,136.25 ^t	4.75 ^v
45 days	31.11 ^b	2.22 ^d	2.21 ^h	138.3 ^j	60.99 ^l	0.30 ^o	4.21 ^q	10,037.02 ^{ts}	4.70 ^v
Control	18.00 ^c	3.67 ^f	1.39 ⁱ	127.8 ^k	80.61 ^m	0.0047 ^p	0.00 ^r	13,071.05 ^u	5.99 ^w
F-value	8.105	874.764	351.192	1.063	4.46	12.180	2.27	9.81	1.934
Significance	S	S	S	0.403 (NS)	0.0968 (NS)	S	0.1850 (NS)	0.0128	0.225 (NS)

S, Significant; NS, Non-Significant. *Same super scripted alphabets represent non-significant difference.

Table 2 Prediction equations of effect of age of nursery on dependent parameters

Eq. no.	Parameter	Prediction equations	Value of R ²
7	Missing Index	= 49.89 – 0.954 A + 0.0119 A ²	0.752
8	Multiple Index	= - 22.856 + 1.559 A – 0.0222 A ²	0.996
9	Damage Percentage	= - 4.997 + 0.652 A – 0.0109 A ²	0.990
10	Hill to Hill Spacing	= 86.754 + 3.158 A – 0.044 A ²	0.619
11	Planting Efficiency	= 42.567 + 0.905 A – 0.011 A ²	0.504
12	Field Capacity	= 0.581 – 0.0156 A + 0.000208 A ²	0.831
13	Fuel Consumption	= 4.99 – 0.049 A + 0.00017 A ²	0.426
14	Cost of Operation	= 7205.97 + 156.558 A – 2.081 A ²	0.783
15	Yield	= - 2.498 + 0.387 A – 0.0051 A ²	0.509

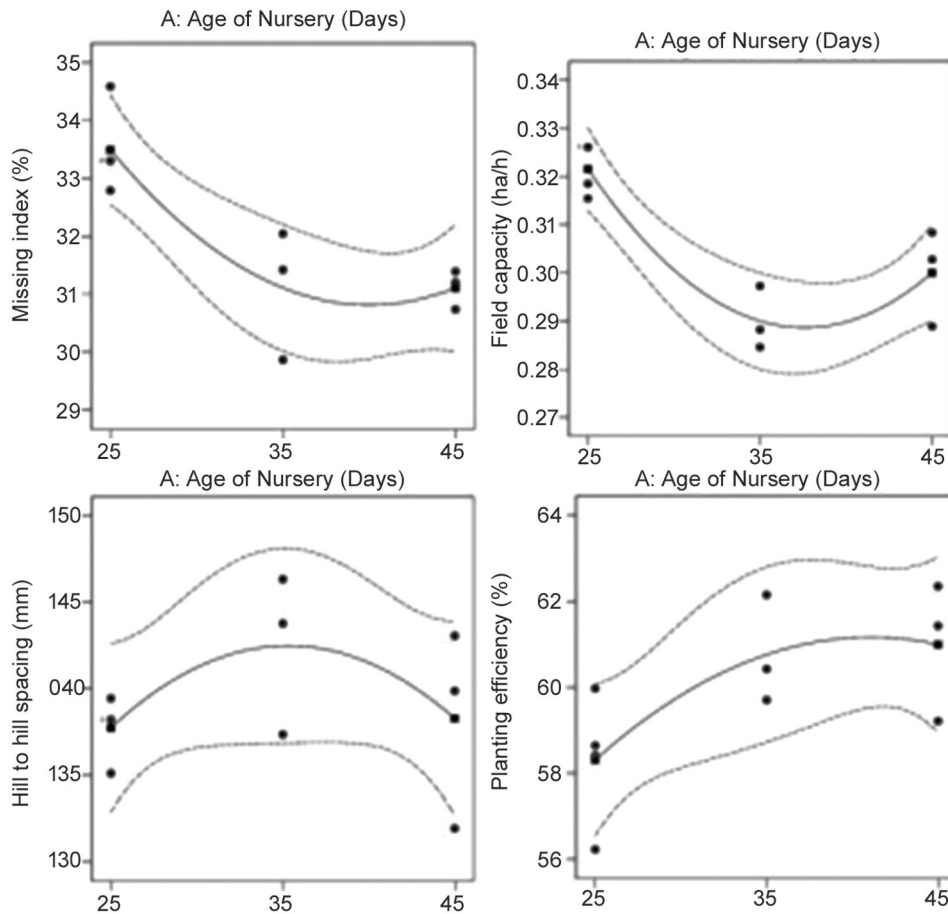


Fig. 3 Effect of age of nursery on dependent parameters.

to-hill spacing, and field capacity of the developed paddy transplanter were 33.11%, 2.21%, 139.5 mm, and 0.32 ha/h, respectively, which were significantly higher compared to control, whereas the multiple index, planting efficiency, cost of operation, and yield were 2.22%, 60.99%, ₹ 9815.49/ha, and 4.75 t/ha, which were lower than those of control. The forward speed, mechanism speed, and age of nursery were optimised to 1.5 km/h, 254 rpm (Rotation per minute) and 35 days of nursery, respectively. Overall, the developed tractor-operated paddy transplanter exhibited a promising performance for the mechanisation for paddy cultivation.

ACKNOWLEDGEMENT

Neeraj Kumar Singh received financial support from the Council for Scientific and Industrial Research, New Delhi. Punjab Agricultural University provided funding and research facilities.

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