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Deepak Kumar
Ph.D. Scholar, ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

Umashanker
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

Deeksha Dey
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

Vijay Kumar
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

RN Pateriya
Department of Farm Machinery and Power Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Anand Kumar TM
Division of Crop Production and Protection, CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, Uttar Pradesh, India

Anvesha Tamta
Department of Food and Public Distribution, Ministry of Consumer Affairs, Food & Public Distribution, Government of India, New Delhi, India

Corresponding Author:
Umashanker
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

Development and performance evaluation of manually operated rice transplanter for Uttarakhand Hilly Region

Deepak Kumar, Umashanker, Deeksha Dey, Vijay Kumar, RN Pateriya, Anand Kumar TM and Anvesha Tamta

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Abstract
A study was conducted to evaluate the influence of seedling age, water depth, and field preparation level on the transplanting performance of a manually operated rice transplanter under hilly conditions. Three levels of field preparation (low, medium, and high), three water depths (0-30 mm, 30-60 mm, and 60-100 mm), and three seedling ages (20, 25, and 30 days) were examined. The results revealed that younger seedlings (20-25 days) transplanted at shallow water depths (0-30 mm) achieved superior performance with the lowest missing hills (4-5%), floating hills (6-7%), damaged hills (3-4%), and buried hills (2-3%). In contrast, older seedlings (30 days) at deeper water levels (60-100 mm) showed higher incidences of missing (10-12%) and floating hills (10-12%), indicating reduced placement accuracy and anchorage. Planting efficiency was highest (83.3%) for 20-day-old seedlings under shallow water at high field preparation, while the lowest efficiency (71%) occurred with 30-day-old seedlings in deep water under low preparation. Overall, high field preparation ensured better soil uniformity and reduced damage, whereas excessive water depth adversely affected seedling stability. The study concludes that using 20-25-day-old seedlings at 0-30 mm water depth under high field preparation optimizes transplanting efficiency and ensures uniform plant establishment in rice cultivation. The developed transplanter demonstrated an actual field capacity of 0.02 ha h^{-1} and a field efficiency of 62.26%, highlighting its potential suitability for small and marginal farmers in hilly regions.

Keywords: Rice transplanter, missing hills, floating hills, planting efficiency, field capacity

1. Introduction

Rice is a major food grain crop and staple food of millions of people in the world. About 90 per cent of rice grown in the world is produced and consumed in Asian countries. In India rice crop is planted in almost all the states and the area under rice cultivation was 43.79 Mha and the total rice production of India was 135.75 MT in 2022-23 (Agricultural Statistics at a Glance 2023, MA&FW). To meet the food demand of the growing population and to achieve food security in the country, the present production levels need to be increased by 2 MT every year. It is estimated that 140 MT of rice is required to feed the growing population by 2022 (Vasudevan *et al.* 2014) [32]. Agriculture is the most important sector of Indian economy. Rice is one of the major cereal crop cultivated in India, a huge amount of workforce is engaged in rice production. Rice crop is generally sown by means of three methods in India, i.e. drilling of seeds, broadcasting of seeds and transplanting of paddy seedlings. Out of these three methods, transplanting of seedlings is the most common practice in India and Asian countries, as it has its own superiority over other two methods, i.e. better weed control and low water requirement and 10-22% more productivity. However the main problem in the production of rice is transplanting operation, which is tedious, tiresome and labour consuming, because a person has to stand in puddled field and bend for putting seedlings into the soil by hand. About 250 to 300 man-hour per hectare is needed for transplanting of paddy. Transplanting work should be completed within optimum period to maintain the timeliness of the operation for getting optimum yield. Scarcity of labour has been experienced during peak period of transplanting work. Hence, there is a great need for mechanisation of transplanting operation in paddy cultivation. (Bhowmik *et al.* 2016) [7]. In Uttarakhand state, about 70% population is living in hilly areas and depends directly or indirectly on agriculture. Uttarakhand (28°43' to 31° 27' N and 77°34' to 81°02' E) is located in the North Western Himalayas and is blessed with the climate favourable for the good production of wide variety of agro-horticultural crops. However, the degree of farm mechanization, mainly in hills is very poor with respect to mechanical power and efficient tools and implements used by the farmers. The hilly regions of the state experience low levels of agricultural mechanization due to undulating terrain, small and uneven fields, and limited availability of suitable machinery. Additionally, factors such as lack of skilled labor, poor repair and maintenance facilities, low purchasing power of farmers, and inadequate access to advanced farm tools further constrain mechanization efforts. The development of gender friendly, lightweight manually operated rice transplanter with ease of transportation from one field to another field is needed with due consideration to purchasing power of farmers and suitability for undulating fields, foothills, Tarai and valley region. To mechanize the transplanting system several attempts have been made to design and fabricate transplanting machines. Due to the high price of an automated paddy transplanter, it becomes impossible for a small scale farmer to purchase a non-subsidized automated paddy transplanter (Bhowmik *et al.*, 2016) [7]. Therefore, the present study was carried out with the following objectives:

1. To develop a manually operated rice transplanter.
2. Performance evaluation of the developed machine.

2. Materials and Methods

The two rows manually operated hand cranked type rice transplanter was developed and fabricated in the workshop of Farm Machinery and Power Engineering Department, College of Technology, Govind Ballabh Pant University of Agriculture and Technology Pantnagar, District Udham Singh Nagar, Uttarakhand, India. The developed machine consisted mainly wooden float, main frame, seedling trays, seedling tray holding frame, picking fingers, planting arms, primary shaft, secondary shaft, driving sprocket, driven sprocket, chain and handle (Fig.1). The specifications of developed manually operated rice transplanter is shown in table.1.

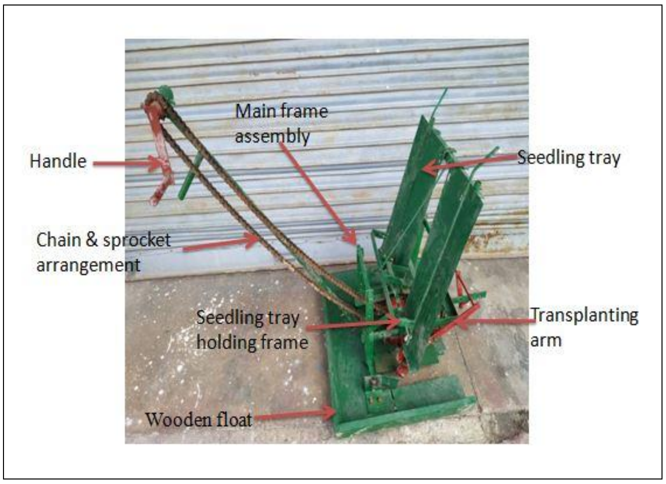

Fig 1: Developed rice Transplanter

Table 1: Specifications of developed manually operated rice transplanter

S. No.	Type	Specification
1.	Over all dimension (L×H×B), mm	
	Length, (L)	1200
	Breadth, (B)	600
	Height, (H)	1100
2.	Weight, kg	17
3.	Type of power source	Manual power
4.	Number of rows	2
5.	Row spacing, mm	300
6.	Plant spacing, mm	140
7.	Type of seedling	Root washed seedling
8.	Type of picking mechanism	Cam and follower
9.	Number of picking finger	2
10.	Number of planting arm	2
11.	Power transmission type	Chain and sprocket

2.1 Shaft design

The shaft was determined according to maximum load distribution at different points.

$$P = \frac{2\pi\ NT}{60 \times 750}$$

Where,

P = Human power

N = No. of revolution of sprocket

T = Torque of the shaft, N-m

For shaft, MS (45C8) was used with yield strength of 330 N/mm^2 and ultimate tensile strength of 600 N/mm^2. According to ASME code, the permissible shear stress for shaft without keyways is taken as 30% of the yield strength or 18% of the ultimate tensile strength, whichever is lower.

According to maximum shear stress theory:

$$d^3 = \frac{16}{\pi} \times \frac{\sqrt{T^2 + M^2}}{\tau_{\max}}$$

where,

d = Diameter of the shaft, mm

T = Torque of the shaft, N-mm

M = Bending moment, N-mm

τ_{max} = Maximum torsional shear stress, N/mm^2

Diameter of the shaft can be calculated…

d = 12.81 mm ≈ 15 mm

For low speed between 10 to 100 rpm, sprocket with only 9 to 11 teeth can be used (Design Data book, CIAE, Bhopal), availability of sprocket of 11 teeth having 20 mm bore in the market, the diameter of shaft considering 20 mm at the safer side.

2.2 Picking mechanism
Cam is rotating machine element imparting reciprocating or oscillating motion to another element known as follower. For the paddy transplanter radial cam having roller type follower was considered. The cam was designed based on opening and closing requirements of picking fingers, which was determined by considering the measurements of nursery (shoot diameter). The cam profile was responsible for grasping seedlings and leave the seedlings for transplanting (Fig.2). The cam profile was marked and cut on M.S. flat plate of 3 mm thickness.

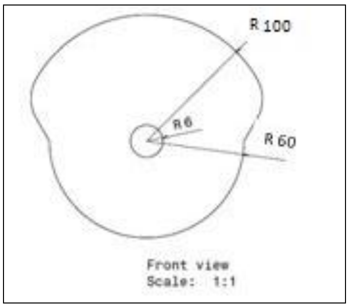

Fig 2: cam profile of picking mechanism

a) Construction of displacement diagram to nursery picking mechanism cam
The maximum intermediate size was 100 mm and minimum size was 60 mm which was measured by considering the measurements of nursery (shoot diameter). Hence 40 mm stroke length was considered for displacement of the picking finger to grasps the shoot of the seedling.

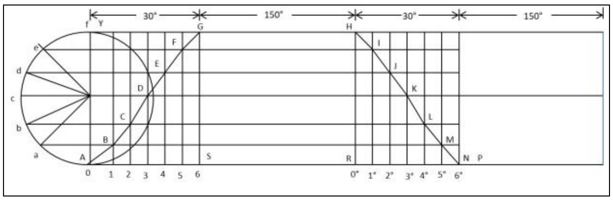

Fig 3: Construction of cam displacement diagram

2.3 Nursery holding mechanism
Cam and roller follower were considered. Stroke length of cam was determined from the size of radial intermediate axis the maximum intermediate size was 140 mm and minimum size was 120 mm which was measured by considering the measurements of nursery (shoot diameter). Hence 20 mm stroke length was considered. The cam profile was marked and cut on M.S. flat plate of 3 mm thickness. With each stroke holding mechanism released the 2-3 seedling for planting arm.

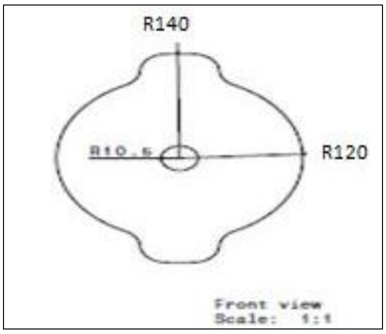

Fig 4: cam profile of nursery holding mechanism

a) Construction of displacement diagram of nursery holding mechanism cam

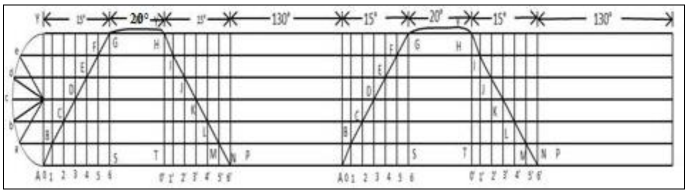

Fig 5: Construction of displacement diagram for nursery holding cam

2.4 Power transmission system
Power was transmitted through the operator's hand by rotating the handle which was connected to the first sprocket. The power was transmitted from sprocket S_1 to sprocket S_2 through the chain. Sprocket S_2 was mounted on the main shaft So that the shaft gets rotations. Sprocket S_3 get the rotation because it was also mounted on the main shaft and transmitted the power to Sprocket S_4 through chain, which was mounted on the secondary shaft. The planting arms were connected to the secondary shaft with flat to get the reciprocating motion and followed the elliptical path.

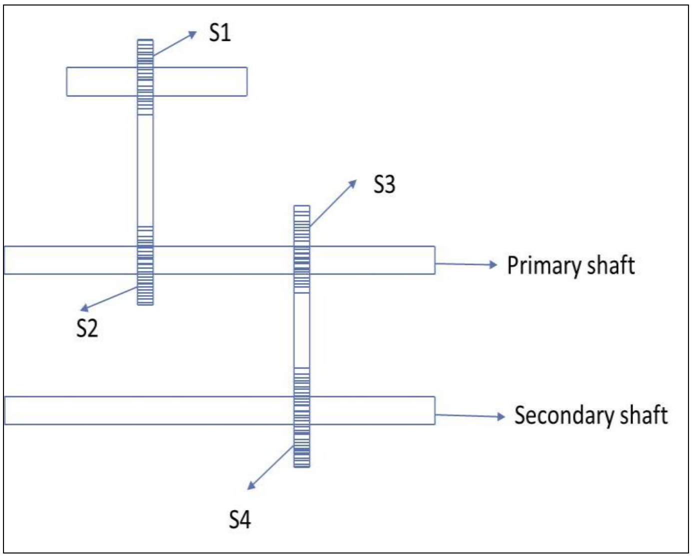

Fig 6: Power transmission system

2.5 Determination of planting speed
The number of planting per minute by the machine can be calculated by.

$$N_p = N_3 \times S.R$$

where,
N_3 = No. of revolution of driving sprocket, rpm
S.R = sprocket velocity ratio

2.6 Determination of total no. of hills per minute

$$N_h = N_p \times N_R$$

where,
N_p = No. of Planting per minute
N_R = No. of Rows

Table 2: Experimental plan

S. No.	Independent parameters	levels
1.	Seedling age, days	20
		25
		30
2.	Water depth, mm	0-30
		30-60
		60-100
3.	Field preparation level	Low
		Medium
		High
	Dependent parameters	
1.	Missing hills,%	The experiment were replicated three times for each treatment
2.	Floating hills,%	
3.	Damaged hills,%	
4.	Buried hills,%	
5.	Planting efficiency,%	

2.7 Root washed seedling preparation

Root washed seedling was required for successful testing of the developed rice transplanter. The Pusa Basmati 1509 paddy seeds was put in to salt water for 15 minutes. Unhealthy seeds were floated on top of used saline water, floated seeds from the solution were removed and remaining seeds were collected and washed twice with fresh water and then put in water for about 24 hours for soaking. Soaked seeds were put in a moist gunny bag for another 24 hours. Sprouted seeds was used for sowing on the field already been prepared. The area of field was selected on the basis of one-tenth of the transplanted area. The second sowing was done after 5 days of first sowing and third sowing after 5 days of second sowing because of this we could get the different days old seedling on same day. Frequent irrigation and recommended dose of fertilizers were given from time to time. After 20 days of the last sowing the nursery ready for transplanting.

2.8 Field preparation

The 27x5 m^2 size test plot was harrowed twice and divided into three sub plot of three different field preparation level (L_1, L_2 & L_3) and water was filled to a depth of about 150 mm. After about 12 hours of watering the field, puddling operation was conducted in the plot using a rotavator. L_1 was low level field preparation mean single pass of rotavator for puddling operation. Similarly, L2 and L3 was used double pass and triple pass of rotavator respectively. After puddling operation, the plot was left undisturbed with standing water in it for a period of 24 hours after which the performance of the transplanter was evaluated.

2.9 Measurement of performance parameters

The dependent parameters were calculated in the following manner as suggested by Singh *et al* (1985) [28].

2.9.1 Missing hills

It indicated that how much constraint remain in picking mechanism of machine. A square quadrant (1 m x 1 m) was used to record the total number of hills and missing hills in a square meter area. The observations were taken, inside the area of square quadrant, from randomly selected four different locations in the field in each replication. An average of all the readings of number of hills missing was taken and number of missing hills in a square meter area was calculated.

2.9.2 Floating hills

Floating hills were the hills where all the seedlings in a hill either floating on surface or just placed on the surface of the mud (Singh *et al.* 1985) [28]. It indicated that how much constraint remain in four bar mechanism. A square quadrant (1 m x 1 m) was used to record the number of floating hills in a square meter area. The observations were taken from randomly selected four different locations in the field in each replication. Number of floating hills in a square meter area was calculated from an average of all the readings.

2.9.3 Damaged hills

Number of hills with all the seedlings damaged either by injury to root or stem (Singh *et al.* 1985) [28]. A square quadrant (1 m x 1 m) was used to record the number of damaged hills in a square meter area. The observations were taken from randomly selected four different locations in the field in each replication.

2.9.4 Buried hills

Hills which are completely buried under the soil after the transplanting are called buried hills (Mori, 1975) [20]. A square quadrant (1 m x 1 m) was used to record the number of buried hills in a square meter area. The observations were taken from randomly selected four different locations in the field in each replication. Number of buried hills in a square meter area was calculated from an average of all the readings.

2.9.5 Planting efficiency

It is the ratio of number of hills with seedlings (planted + floating + damaged + buried) to the total number of hills expressed in percentage.

3. Results and Discussion

The developed Rice transplanter was tested for its performance. The test was conducted in puddled field as per test code and procedure provided by RNAM (1995) at the field of Norman Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture and Technology Pantnagar, District Udham Singh Nagar, Uttarakhand, India. The results pertaining to the performance evaluation of manually operated two row paddy transplanter in actual field condition with different seedling age groups, at three different water depths in three levels of field. The performance parameters namely, missing hills, floating hills, damage hills, buried hills and planting efficiency were determined. The performance of the manually operated rice transplanter under three field preparation level (L_1, L_2 & L_3) was evaluated for different seedling ages (20, 25, and 30 days) across three water depths (0-30, 30-60, and 60-100 mm). The results for missing hills, floating hills, damaged hills, and buried hills are presented in Fig.7,8 & 9.

3.1 Low Field Preparation Level

Under low field preparation, transplanting performance was strongly influenced by seedling age and water depth. The percentage of missing hills (MH) was lowest (4-5%) for 20-day-old seedlings transplanted in shallow water (0-30 mm), while deeper water (60-100 mm) and older seedlings (30 days) resulted in the highest MH (up to 10%). Floating hills (FH) followed a similar trend, ranging from 7% under shallow water to 11% under deeper conditions, particularly with older seedlings (Singh *et al.* 1985) [28]. Damaged hills (DH) remained low (4-6%) at shallow depths but increased at deeper levels due to greater mechanical stress and reduced seedling flexibility. Buried hills (BH) showed minimal variation (2-5%), indicating that water depth had a greater effect than seedling age on burial. Overall, the combination of young seedlings (20 days) and shallow water (0-30 mm) produced superior transplanting results, with fewer missing, floating, and damaged hills. This highlights that insufficient puddling and uneven soil under low preparation amplify transplanting inconsistencies, emphasizing the need for better field levelling and water management for efficient manual transplanting operations.

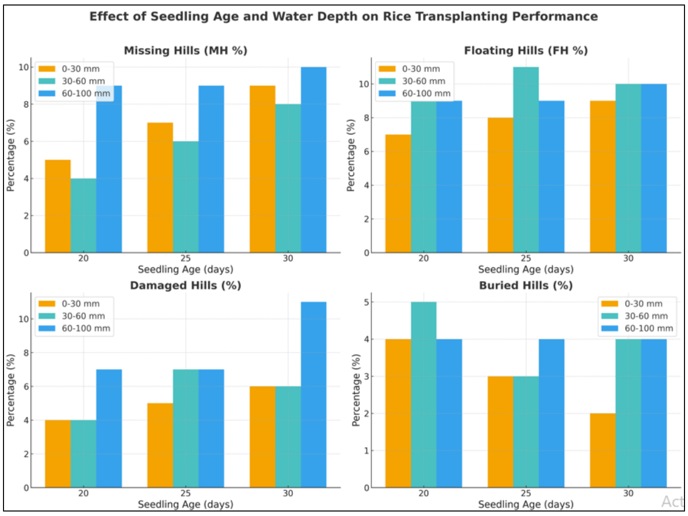

Fig 7: Effect of seedling age and water depth on performance parameters in low level field preparation

3.2 Medium Field Preparation Level

At the medium field preparation level, transplanting performance improved due to better soil tilth and uniformity. Missing hills (MH) ranged from 5-6% at shallow depths to 9-12% at deeper levels (60-100 mm), with 30-day-old seedlings performing poorest. Floating hills (FH) displayed an increasing pattern with water depth and seedling age, from 6-8% at 0-30 mm to 9-12% at 60-100 mm. The higher FH percentages in deep water suggest poor seedling anchorage caused by excessive buoyancy. Damaged hills remained moderate (3-6%), lowest under shallow water with young seedlings and highest at deeper depths, reflecting the mechanical stress during planting. Buried hills (4-6%) increased slightly with depth, but were less affected by seedling age. The medium field preparation provided improved soil uniformity and reduced seedling stress, but excessive water depth still reduced transplanting precision. Thus, maintaining shallow water and using younger seedlings (20-25 days) under medium field preparation optimizes transplanting quality, ensuring lower incidences of missing and floating hills while maintaining acceptable damage and burial levels.

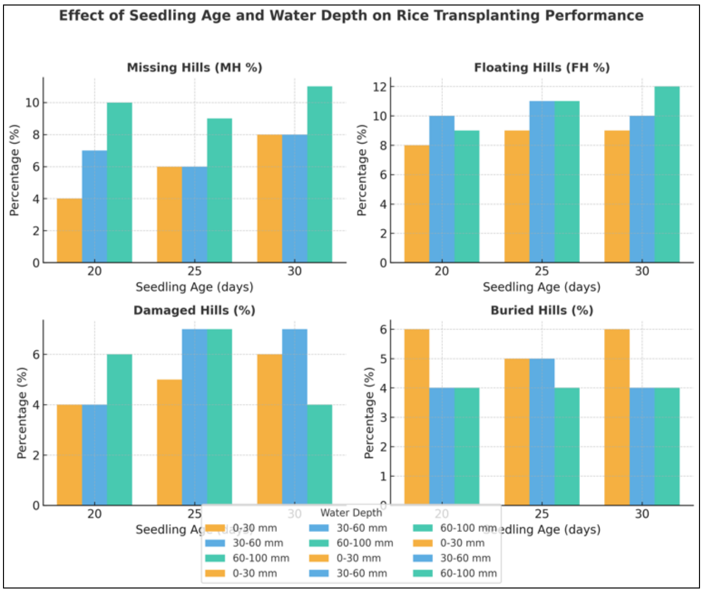

Fig 8: Effect of seedling age and water depth on performance parameters in medium level field preparation

3.3 High Field Preparation Level

High field preparation exhibited the most favourable transplanting conditions due to enhanced puddling and soil uniformity. Missing hills (MH) and floating hills (FH) were lowest (5-6% and 6-8%, respectively) at 0-30 mm water depth but increased up to 12% at 60-100 mm, especially with 30-day-old seedlings. Damaged hills (DH) remained between 3-6%, with the least damage observed at 20-day-old seedlings in shallow water. Buried hills (BH) were stable (4-6%), slightly higher in deeper water, likely from soft soil and over-puddling (Mori, 1975) [20]. Overall, the results confirmed that younger seedlings (20-25 days) combined with shallow water depth (0-30 mm) achieved uniform planting and minimal transplanting losses under high field preparation. While high preparation improved planting precision, excessive water depth negatively affected hill establishment due to poor seedling anchorage. Therefore, optimizing field moisture and seedling age is essential for maximizing mechanical transplanting efficiency. These findings collectively demonstrate that high field preparation, coupled with shallow water and younger seedlings, provides the best balance between seedling placement accuracy, reduced hill damage, and uniform establishment in manually operated rice transplanters.

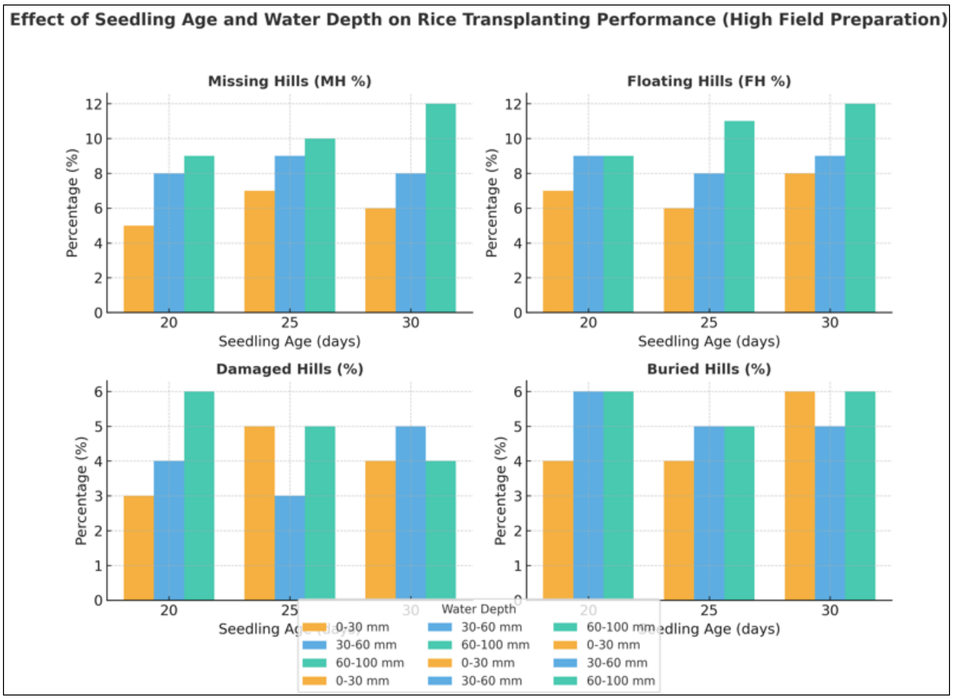

Fig 9: Effect of seedling age and water depth on performance parameters in high level field preparation

3.4 Planting efficiency

Planting efficiency is the ratio of the total number of hills (planted + floating + damaged + buried) per square meter to the total number of hills per square meter expressed in percentage. The effect of seedling age, water depth, and field preparation level on planting efficiency is illustrated in Figure 1. Planting efficiency exhibited a declining trend with an increase in seedling age and water depth across all field preparation levels. For the L1 field preparation, the highest planting efficiency (83.3%) was recorded for 20-day-old seedlings at a water depth of 0-30 mm, while efficiency decreased under deeper water and older seedlings. In L2 preparation, efficiency remained relatively stable, attaining a maximum of 79.8% for 25-30-day-old seedlings at shallow water depth. The L3 level showed comparatively lower efficiencies, ranging between 71.5% and 79.8%, possibly due to poor soil tilth and uneven field surface, which impeded uniform planting. Overall, the results indicate that shallow water depth (0-30 mm), younger seedlings (20-25 days), and well-prepared fields (L1 and L2) provide optimal conditions for the manually operated rice transplanter. These conditions enhance machine traction, seedling placement, and overall operational efficiency.

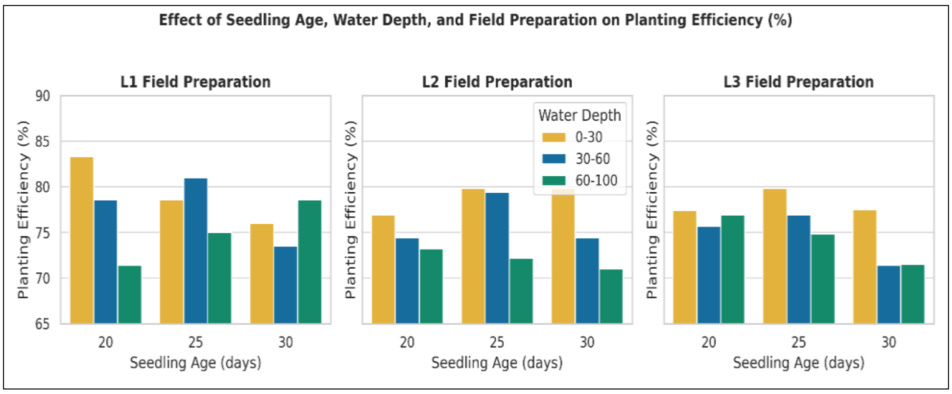

Fig 10: Relation between various water depth and planting efficiency for different seedling age groups in all level field preparation

The values showed that the planting efficiency reduced with increase in seedling age. This may be due to the fact that the tenderness of seedling shoot, root growth and length of the seedlings changes with the age of seedlings and affected the picking of seedling from the tray resulted in lower percentage of planting efficiency. More growth of roots caused interlocking which prevented the seedlings to get separated and released from the tray. The values showed that the planting efficiency reduced with increase in water depth. This may be due to the wooden float floated in higher water depth and travel more with less pulling force causing an increase in missing hills.

Table 3: Analysis of variance water depth, seedling age and field preparation level

Source	Sum of Squares	DF	Mean Square	F Value	p-value
A-Water depth	129.50	2	64.75	4.79	0.002
B-Seedling age	357.30	2	178.66	13.22	0.0001
C-Preparation level	112.05	2	56.02	4.14	0.001
AB	50.06	4	12.51	0.92	0.0012
AC	88.60	4	22.15	1.63	0.17
BC	189.55	4	47.38	3.50	0.012
ABC	78.80	8	9.85	0.72	0.66
Error	729.75	54	13.51		
Total	1735.68	80			

The ANOVA results reveal that water depth (A), seedling age (B), and field preparation level (C) all had significant effects on transplanting performance, as indicated by their p-values < 0.05. Water depth showed a statistically significant effect ($F = 4.79$, $p = 0.002$). This indicates that variations in water level during transplanting significantly influenced the establishment and stability of transplanted hills. Higher water levels likely increased the incidence of missing and floating hills due to reduced soil-seedling contact and weaker anchorage. Seedling age had the most pronounced effect among the main factors ($F = 13.22$, $p < 0.0001$). This suggests that the physiological maturity and vigor of seedlings strongly determine transplanting efficiency. Younger seedlings (20-25 days) typically establish better due to their flexibility, while older seedlings (30 days) tend to suffer higher transplanting losses. The level of field preparation also significantly influenced transplanting outcomes ($F = 4.14$, $p = 0.001$). Well-leveled and properly puddled fields (high preparation) improved uniformity in transplanting depth and reduced mechanical planting errors, leading to more consistent plant stands.

The interaction between water depth and seedling age was statistically significant ($p = 0.0012$), implying that the combined effect of these two factors influenced transplanting performance. The optimal combination of younger seedlings (20-25 days) with shallow water (0-30 mm) minimized transplanting errors, whereas older seedlings in deeper water led to higher missing and floating hill percentages. The AC interaction was not significant ($p = 0.17$), suggesting that the influence of water depth was relatively consistent across different field preparation levels. This means that regardless of the level of soil puddling, deeper water consistently increased transplanting errors. The interaction between seedling age and field preparation level was significant ($p = 0.012$). This indicates that the effect of seedling age varied depending on the degree of field preparation. Younger seedlings performed best under high field preparation, which provided uniform soil texture and better root anchorage. The three-way interaction among the factors was non-significant ($p = 0.66$), implying that the combined influence of water depth, seedling age, and preparation level did not produce additional synergistic effects beyond their individual and two-way interactions.

The ANOVA findings demonstrate that transplanting performance is primarily governed by seedling age, followed by water depth and field preparation level. The significant two-way interactions (AB and BC) highlight the importance of optimizing the combination of seedling physiological condition and field management practices to achieve uniform establishment. Specifically, younger seedlings transplanted in shallow water under well-prepared fields exhibited the best establishment, minimal hill losses, and improved uniformity. In contrast, older seedlings and deeper water conditions led to higher rates of missing, floating, and damaged hills, consistent with previous reports emphasizing the role of water management and seedling vigor in mechanized rice transplanting. Overall, these results underscore the necessity of maintaining shallow water depth (≤30 mm) and using 20-25-day-old seedlings in well-prepared fields to maximize transplanting success and ensure optimal rice stand establishment.

3.5 Actual field capacity and field efficiency of the rice transplanter

Based on the results obtained from the field test, the performance of rice transplanter was found better at average forward speed of 0.5 km/h. The average theoretical field capacity of the rice transplanter was worked out to be 0.03 ha/h. The productive and unproductive time taken by the rice transplanter to cover 45 m^2 (5 m width x 9 m length) area was noted. The average actual field capacity and field efficiency of the rice transplanter was achieved as 0.02 ha/h and 62.26% respectively.

4. Conclusion

The percentage of floating hills, missing hills, damaged hills and buried hills was found significantly varying with change in level of water depth, seedling age and level of field preparation. Depth of water and age of seedlings was found having significant effect on planting efficiency. Across all treatments, younger seedlings (20-25 days) and shallow water depth (0-30 mm) consistently achieved the lowest percentages of missing, floating, damaged, and buried hills. High field preparation provided superior soil tilth and uniform seedling placement, though excessive water depth reduced transplanting accuracy. In contrast, low field preparation increased variability in planting quality due to uneven soil conditions. Overall, optimal transplanting performance can be achieved under well-prepared fields with shallow water and younger seedlings, ensuring better plant establishment, reduced transplanting losses, and enhanced operational efficiency in hilly rice-growing regions. The actual field capacity and field efficiency of developed transplanter has been observed as 0.02 ha/h and 62.26% respectively. The operating cost of machine was Rs. 2900 per hectare and total saving was 62.80% of total cost of traditional paddy transplanting. From the study, it can be concluded that the developed transplanter could be used for transplanting of paddy seedlings with maximum field efficiency and planting efficiency with less seedling damage.

Authors contribution

Deepak Kumar: Writing - original draft, Conceptualization, Visualization, Data curation, Methodology, Investigation. Umashanker: Writing - review & editing, Validation, Methodology, Investigation, Conceptualization. Deeksha Dey:

Writing - review & editing, Statistical validation. Vijay Kumar: Methodology, Investigation, Writing - review & editing. Anand Kumar TM: Formal analysis, Data curation, Writing - review & editing. Anvesha Tamta: Methodology, Formal analysis, Writing - review & editing.,

Declaration of competing interest

The authors state that they have no disclosed financial conflicts or personal associations that might have influenced the research presented in this paper.

Data availability

Data will be made available on reasonable request from the corresponding author.

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