**Field Evaluation of Two-row Root Wash Type Paddy Transplanter**

**Abstract**

Rice is one of India's most important food crops, and its cultivation includes tedious and labour-intensive processes. Although the number of paddy transplanters in Odisha in the past 10 years has climbed to 2990, the majority of the area is still under manual transplantation. The acceptance of mechanical transplanters is lower due to the extra cost, skill, and time required to raise the mat-type seedlings used in these transplanters. Root wash type paddy transplanter has been a long-awaited demand by farmers. Keeping this in mind, a suitable root wash type transplanter has been developed in CAET which can use the traditional root wash type seedlings used by the farmers. The field evaluation of the same was done to evaluate its performance. The percentage of missing hills, floating hills, buried hills and damaged hills were observed to be 5.65, 4.25, 4.25 and 1.40 per cent, respectively. The total unproductive hill was calculated to be 15.58 per cent, which was higher than the recommended value of 10 per cent. The actual field capacity, theoretical field capacity and field efficiency were found to be 0.0179 ha/h, 0.0265 ha/h and 67.24 per cent, respectively. The average increase in the heart rate and oxygen consumption rate were found to be 60 bpm and 0.63 l/min. The fabrication cost of the transplanter was found to be ₹4960.00 and the cost of transplanting per ha was observed to be ₹2631.00 which saves about ₹6119 per hectare against manual transplanting (₹ 8750.00). Above all, this particular developed Transplanter has several ergonomical benefits like it improves efficiency, reduces physical strain, lowers injury risk, minimizes fatigue,and enhances comfort by enabling upright posture and mechanized transplanting.

**Keywords:** Transplanter, Root wash, Performance evaluation, Field capacity, Cost economics, Design

**Introduction**

Rice (*Oryza sativa* L.) is the most widely consumed staple food in the world, especially in Asia, which alone accounts for around 90 per cent of the total rice production. It is one of the most important food crops of India and is second in importance throughout the world. India has the largest area (51 million ha) under cultivation with a total production of 220 million tonnes (2024-25), in terms of volume of output, it has surpassed China. (India Rice Area, Yield and Production, USDA)

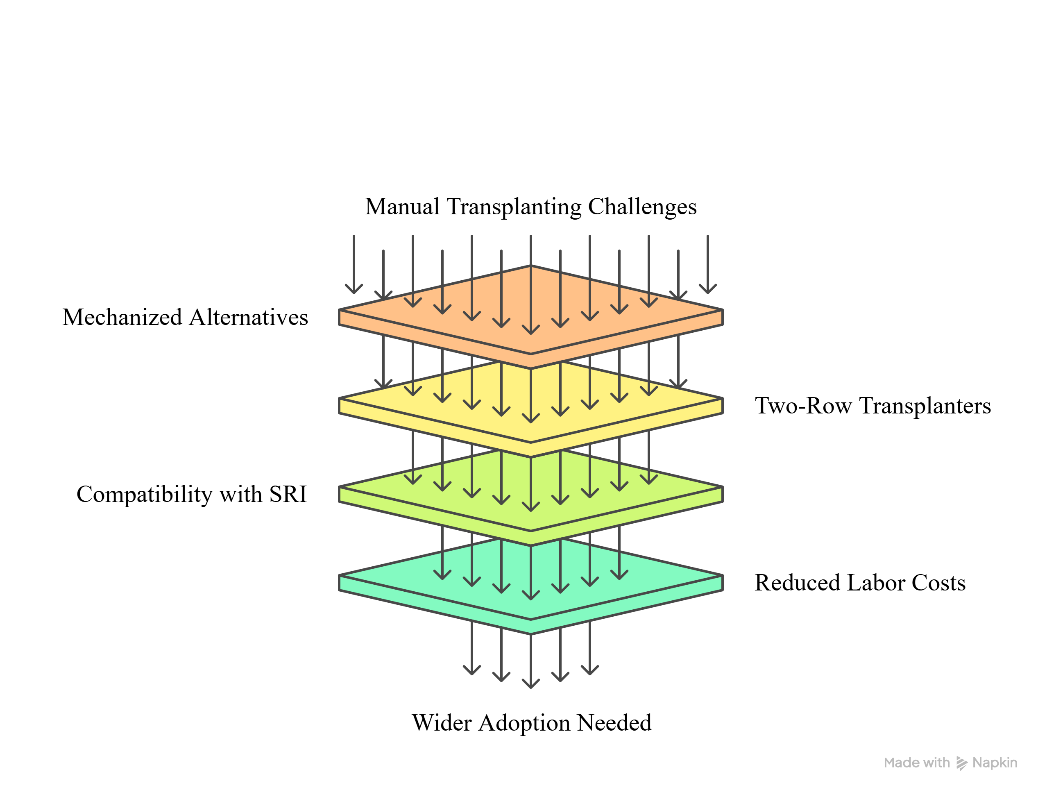
During the 1950s, Odisha ranked among the top rice-producing states in India and contributed significantly to the central food grain reserves. Cultivation of rice is a major component of agriculture in Odisha, where it is equated with food. Rice covers about 67 per cent of the cultivated area and is the major crop, covering about 63 per cent of the total area under food grains. Rice in Odisha is now grown on an area of 4.16 million ha, which accounts for 91 per cent of the area under cereals and contributes about 94 per cent of total cereal production in the state with a total production of 8.33 million tonnes(Directorate of Economics & Statistics, DAC & FW).

Rice is grown mostly in rainfed areas that receive heavy annual rainfall. It is grown mainly in the Kharif and Rabi season. The Kharifseason accounts for 88 per cent and Rabi season accounts for 12 per cent of total rice production. Therefore, it is fundamentally a Kharif crop in India. It demands temperature of around 25°C and above and rainfall of more than 1000 mm.

Rice is generally grown by the traditional method of transplanting which is expensive, involves lots of drudgeries, has huge labour requirements and takes about 250-300 man hours/ha which is roughly 25 per cent of the total labour requirement of the crop (Chaudhary *et al*., 2005). Despite this, uniform hill and row spacing were not achieved due to which it is unsuitable for mechanical weeding. Suitable plant density and timeliness in operation is a must for paddy cultivation in order to optimize paddy yield which is possible only if dependence on hired labour is minimized (Garg *et al*., 1984). Selective mechanization offers a practical and scalable solution to enhance rice cultivation productivity, particularly in regions with labour shortages and fragmented landholdings (Yadav *et al*., 2013).

Most of the mechanical transplanters available in the market use mat type seedlings for transplanting operation (Kannan *et al*., 2021, Dewangan *et al*., 2005). Mat type nursery requires special materials and the extra time and labour for raising seedlings (Singh *et al*., 2002).

Considering the growing shortage of manpower, high input prices, and requirement of timely operations, mechanized rice transplanting has become a crucial intervention for improving the productivity and profitability of rice production. Despite being common, manual transplanting is time-consuming, labor-intensive, and ergonomically demanding, which can result in irregular plant stands and delayed transplanting. Mechanized alternatives that increase planting uniformity, operational speed, and field efficiency include self-propelled and manually operated transplanters (Dixit et al., 2007; Chandra et al., 2013; Lohan et al., 2022). Due to their inexpensiveness and ease of use, two-row manually operated transplanters are particularly well-suited for small and marginal farmers (Ganapathi et al., 2015; Asha et al., 2020; Pal et al., 2018). Plant establishment and transplanting efficiency are further improved by these machines' compatibility with root-washed seedlings, especially when used in conjunction with the System of Rice Intensification (SRI) (Mishra et al., 2021; Singh et al., 2023; Pal et al., 2018). Recent developments have shown that these devices are technically feasible for increasing plant placement and field capacity while drastically lowering labor costs (Sebastian et al., 2023; Meris et al., 2020). Field-level adoption is still quite low despite these developments, which emphasizes the necessity of a thorough assessment of their performance in a range of agroclimatic circumstances. In order to facilitate its wider adoption in mechanized rice production systems, this study is to evaluate the field performance and operational feasibility of a two-row root wash type paddy transplanter. The transition from traditional to mechanized farming can be understood by advantages that are associated with it as shown in Fig 1.



**Fig 1.** Transitioning to mechanized transplanting

Many Indian rice farmers continue to use traditional seedling preparation methods involving soil-based nurseries, which produce uprooted or root-washed seedlings. While mechanization in rice transplanting has advanced, most machines remain suited only for mat-type seedlings, limiting their usefulness for farmers who prefer conventional nursery practices (Mishra et al., 2021). This mismatch between available technology and traditional practices has hindered the widespread adoption of mechanical transplanting, especially among small land holders. To address this gap, a two-row root-wash type paddy transplanter was developed at the College of Agricultural Engineering and Technology (CAET), which offers compatibility with conventional seedlings. This machine enables precise planting depth and spacing, ensuring field performance comparable to manual transplanting but with reduced labor input (Sebastian & Thomas, 2023). The compatibility of such machines with existing seedling practices enhances their adoption potential, as evidenced by recent research on similar technologies designed for root-washed seedlings (Singh et al., 2023). Furthermore, optimized transplanting methods using root-washed seedlings have been shown to improve plant establishment and yield uniformity (Lohan et al., 2022), while also reducing planting fatigue and time requirements for farmers (Meris et al., 2020).

**Materials and method**

The conventional method of transplanting is exhausting and ergonomically unsuitable for the workers, generally women and the transplanters using mats doesn’t attract the farmers due to extra investment and complicacies of growing seedlings (Mohanty *et al*., 2012). Therefore, the development of the transplanter was done keeping in mind that it would be able to transplant conventional rice seedlings i.e. uprooted root washed seedlings. The major components of the transplanter includes the main frame, float, drive wheel, chain and sprocket power transmission system, eccentric disc, finger assembly, seedling tray and the handle. The specification of the developed transplanter was given in Table 1.

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| --- | --- | --- |
| **Table 1.** Specification of the modified transplanter | | |
| **Sl. No.** | **Details** | **Specification** |
|  | Machine type | Manual |
|  | Overall dimensions in mm   1. Length 2. Width 3. Height | 850  390  500 |
|  | Weight, kg | 19.3 |
|  | Float   1. Shape 2. Length 3. Width | Irregular  650  390 |
|  | Drive wheel   1. Diameter, mm 2. No of lugs | 440  12 |
|  | Finger   1. Type 2. Length, mm 3. Width, mm 4. Gap, mm | Wire loop  300  25  4 |
|  | Tray   1. Number of chambers 2. Width, mm 3. Height, mm | 02  225  500 |
|  | Handle   1. Length, mm 2. Width, mm 3. Grip spacing, mm | 900  400  200 |
|  | Planting rows   1. Number 2. Spacing, mm | 02  250 |
|  | Planting finger actuating mechanism | Eccentric |
|  | Number of people required for operating the machine | 01 (one) |

**Working of the developed transplanter**

The drive wheel shaft and the eccentric disc shaft are connected via chain and sprocket. As the drive wheel rotates the eccentric disc also rotates. The connecting rod connects the eccentric disc and the finger assembly (Asha and Ray, 2020). The eccentric disc converts the rotary motion of the shaft into the reciprocating motion of the finger assembly which takes 2-3 seedlings from the tray and transplant it in the puddled soil at a plant to plant distance of 17 cm.

**Nursery raising**

The traditional nursery which the farmers use for manual transplanting was used in the mechanical transplanting of rice. Quality of the nursery and the puddling of the field are the two main factors which affect the efficiency of the machine (Behera *et al*., 2009). Therefore, proper care was taken while preparing the nursery and the field for testing. For raising nursery, a raised bed of 8x1 m was prepared on levelled ground. The surface of the bed was levelled, compacted and smoothened. Seeds of paddy variety ‘Lalat’ was selected for the experiment. The selected seeds were dipped in 15-16% salt solution. Then the seeds were kept in warm water with a 40-degree temperature for 24 hours. Then the seeds were removed and kept in moist gunny bag for germination. Paddy seeds after germination were broadcasted uniformly at the rate of 75 kg/ha over the puddled field prepared (Ehsanullah *et al.*, 2007). Proper care was taken with proper irrigation as required.

**Methodology for measuring field parameters**

The field evaluation of the modified transplanter was conducted in the Agronomy Main Research Farm, OUAT, Bhubaneswar of Khurda district, Odisha during Rabi season of 2018-19 as per the test code and procedure provided by RNAM (1995). The preliminary studies indicated that the optimum age of seedlings to be 20 days with sedimentation period of 48 hours (Goel *et al*., 2008, Kavitkar *et al*., 2017). Therefore, the field evaluation was carried out in the above condition. The field was prepared using rotavator with a depth of operation kept at 15 cm. The field was left for soil settlement and transplanting was done at 2-3 cm depth of water after 48 hours. The filed was divided into 3 subplots in order to replicate the experiment for minimizing any type of variation present in the soil and field condition. The field size for the testing was 15x6 m2.

**Field Parameters studied**

**Row spacing**

Row to row between consecutive hills were measured using steel tape. Ten observations were noted from different locations in the field to get the average row to row spacing.

**Hill spacing**

Hill spacing between consecutive hills was measured using a measuring tape (Garg et al., 1997). Ten observations were noted from different locations in the field to get the average hill spacing. Missing hills, floating hills, damaged hills and buried hill were observed and reported.

**Missing hills**

Missing hills occur due to non-transplanting of seedlings in the hills. Missing hills per square meter area were found by putting a square frame (1m x 1m) randomly in the field and counting the number of missing hills inside the square frame (Deres and Katahira, 2024). Ten such readings were noted randomly from the field in order to get the average missing hills per square meter. Missing hill percentage is given by the following equation

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| --- | --- |
|  |  |

**Floating hills**

Floating hills are those hills in which the seedlings transplanted were floating on the surface after 24 hours of transplanting. Floating hills per square meter were observed after 24 hours of transplanting by putting square frames randomly in the field. Ten such readings were noted randomly from the field in order to get the average floating hills per square meter. Floating hill percentage is given by the following equation

|  |  |
| --- | --- |
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**Buried hills**

Buried hills refer to hills in which the seedlings were buried completely under the puddled soil after transplanting. It is measured per square meter by putting a square frame randomly in the field. Ten such readings were noted randomly from the field in order to get the average buried hills per square meter. Buried hill percentage is given by the following equation

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**Damaged hills**

Seedlings that are damaged due to the action of the finger during the transplanting operation are referred to as damaged hills (Manikyam *et al*., 2020). It is measured by putting the square frame randomly in the field and counting the damaged hills per square meter. Ten such readings were noted randomly from the field in order to get the average damaged hills per square meter. Damaged hill percentage is given by the following equation

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**Draft**

A spring balance of 50 kg-f capacity was used for measuring the draft. The spring balance had two hook links. One hook link was connected to the transplanter handle and while the other end was pulled manually. Then the angle of the pull was measured. It is given by the following equation

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Where, P = force required to pull, kg-f

= angle of pull, degrees

**Theoretical field capacity**

It is the rate of field coverage that would be obtained if the machine performs its function 100 per cent of the time at rated forward speed and always covered 100 per cent at its rated width. It is given by the following equation

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|  |

Where, w = Width of the implement, m

s = Speed of operation, km/h

**Actual field capacity**

It is the actual rate of coverage of the field by the machine. Actual field capacities will be less than their theoretical capacities . It is given by the following equation

|  |  |
| --- | --- |
|  |  |

Where, w = Actual width of the implement used, m

s = Speed of operation, km/h

**Field efficiency**

This gives an indication of the time lost in the field and fails to utilize the full working width of the machine. It is the ratio between the actual field capacity and theoretical field capacity, expressed as a percentage (Shahare *et al*., 2011). It is given by the following equation

|  |  |
| --- | --- |
|  |  |

Where, AFC = Actual field capacity, ha/h

TFC = Theoretical field capacity, ha/h

**Cost of operation**

Cost of operation of the transplanter was calculated on the hourly basis and subsequently converted in to cost per hectare. Cost was calculated as per the methods followed by Mohanty *et al*., 2010.

**Payback period**

The payback period is the time needed to recover the money invested at different levels of annual usage for the machine. It is given by the following equation

|  |  |
| --- | --- |
|  |  |

**Ergonomic evaluation**

Three subjects were selected from 20 to 35 years age group because maximum strength and power can be obtained in this age group (Gite and Singh, 1997)**.** The heart rate was measured using the polar heart rate monitor (Model S-810) during the transplanting operation with an accuracy of ±1 beats/min. Transplanting operation was done after 48 hours of sedimentation period at various speed of operation. The Initial heart rate before the operation and heart rate after transplanting were recorded. The Oxygen consumption rate (VO2) of the selected subjects were measured using K4b2. The K4b2 unit consists of a transmitter and receiver unit. Transmitter unit was fixed on the subject’s back using an anatomic harness as it was a portable unit. The transmitter unit consisted of the oxygen (O2) and carbon dioxide (CO2) analysers, sampling pump, barometric sensors and was powered by rechargeable battery. The receiver unit was connected to a laptop through the RS 232 serial port. The readings were recorded and can be obtained from the laptop.

**Results and Discussion**

**Field performance evaluation.**

The field performance data were recorded and tabulated below in Table 2. The average hill spacing and row spacing was found to be 17.5 cm and 25.0 cm respectively. The variation in the hill spacing was found due to slippage of the drive wheel. The percentage of missing hills, floating hills, buried hill and damaged hills were observed to be 5.65%, 4.25%, 4.25% and 1.40% respectively. The total unproductive hills/m2 was calculated to be 15.58% which was higher than the recommended value of 10%. The actual field capacity, theoretical field capacity and field efficiency were found to be 0.0179 ha/h, 0.0265 ha/h and 67.24 per cent respectively.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Table 2.** Field performance parameters of the transplanter | | | | | | |
| **Sl. No.** | **Parameter** | **Transplanting replications** | | | | |
| **T1** | **T2** | | **T3** | **Average** |
|  | Date of transplanting | 24/04/19 | | | |  |
| 1. | Hill spacing, cm | 17.5 | 17.8 | 17.2 | | 17.5 |
| 2. | Row spacing, cm | 25.0 | 25.0 | 25.0 | | 25.0 |
| 3. | No of seedlings/hill | 2 | 1 | 3 | | 2 |
| 4. | Missing hills/m2 | 2 | 0 | 2 | | 1.33 (5.65%) |
| 5. | Floating hills/m2 | 1 | 2 | 0 | | 1 (4.25%) |
| 6. | Buried hills/m2 | 0 | 1 | 2 | | 1 (4.25%) |
| 7. | Damaged hills/m2 | 1 | 0 | 0 | | 0.33 (1.40%) |
| 8. | Total unproductive hill/m2 | 4 | 3 | 4 | | 3.66 |
| 9. | Total unproductive hill/m2, % | 17 | 12.75 | 17 | | 15.58 |
| 11. | Speed of operation, km/h | 1.02 | 1.22 | 0.98 | | 1.07 |
| 12. | Theoretical field capacity, ha/h | 0.0250 | 0.0305 | 0.0245 | | 0.0265 |
| 13. | Actual field capacity, ha/h  h/ha | 0.0168  (59.52) | 0.0209  (47.84) | 0.0160  (62.50) | | 0.0179  (55.86) |
| 14. | Field efficiency, % | 67.22 | 68.80 | 65.71 | | 67.24 |
| 15. | No. of persons required for operating the machine | 1 | 1 | 1 | | 1 |

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| **Fig 2.** Unproductive hills in the developed transplanter |
|  | |
| **Fig 3.** Machine parameter of the developed transplanter | |

**Ergonomic evaluation**

**Heart rate**

The Initial heart rate before the operation and heart rate after transplanting were recorded. The table below shows the increase in the heart rate of the subjects during the transplanting operation.

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| --- | --- | --- | --- | --- | --- | --- |
| **Table 3.** Heart rate of the Selected subjects | | | | | | |
| **Sl. No** | **Age of subjects, years** | **Height, cm** | **Weight, kg** | **Initial heart rate,**  **bpm** | **Heart rate after 30 min of work, bpm** | **Increase in heart rate ∆HR, bpm** |
| 1. | 25 | 176 | 76 | 72 | 128 | 56 |
| 2. | 28 | 163 | 63 | 74 | 135 | 61 |
| 3. | 33 | 158 | 52 | 75 | 138 | 63 |

The age of the subjects selected for operating the transplanter varied between 25 to 33 years. The height of the subjects was measured to be 176, 163 and 158 cm with a corresponding weight of 76, 63 and 52 kg. Heart rate before the starting of the operation. i.e., Initial heart rate was 72, 74 and 75 bpm respectively and after 30 minutes of the operation, the heart rate increased to 128, 135 and 138 bpm respectively. The heart rate of the subjects steeply increases with the duration of the operation. The increase in heart rate of 56, 61 and 63 bpm it was found to be within the permissible limit for operation without fatigue. Similar results were reported by Aware et al., 2017.

**Oxygen consumption rate**

The values of OCR were recorded during the operation and has been tabulated below.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Table 4.** Oxygen consumption rate of the Subjects | | | | | | |
| **Sl. No** | **Age of subjects, years** | **Height, cm** | **Weight, kg** | **Initial OCR,**  **l min-1** | **OCR after 30 min of work,**  **l min-1** | **Increase in OCR,**  **l min-1** |
| 1. | 25 | 176 | 76 | 0.15 | 0.65 | 0.5 |
| 2. | 28 | 163 | 63 | 0.24 | 0.84 | 0.6 |
| 3. | 33 | 158 | 52 | 0.21 | 1.02 | 0.81 |

During the transplanting operation, the oxygen consumption rate (OCR) observed to vary from 0.65 – 1.02 l/min. Increase in the OCR was varied from 0.5 – 0.81 l/min which was found be within the limit. The operation was rated as moderately heavy

**Cost economics of the transplanter**

The cost of the modified transplanter and the cost of operation per hour was found to be ₹ 4960.00 and ₹ 47.10 respectively. Considering the field capacity of the transplanter, the cost of transplanting was found to be ₹ 2631.00 per hectare as against ₹ 8750.00 in case of manual transplanting. Hence, the modified transplanter saved about 69.93% of the cost of transplanting over manual transplanting.

**Payback period**

The payback period would be 0.86 years if one hectare of land is transplanted with the modified transplanter. The payback period declined gradually with an increase in the annual area of coverage. The payback period of developed transplanter is shown in Fig 4.

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**Fig 4.** Payback period for the developed transplanter

**Conclusion**

In summary, the assessment of the modified rice transplanter showed significant gains in labour savings, planting accuracy, and operating efficiency. The transplanter minimised planting errors including missing, floating, buried, and damaged hills while ensuring consistent spacing (25 × 17.5 cm) with an ideal seedling age of 20 days and a sedimentation time of 48 hours. The machine's practical efficacy in actual field settings was shown by its 67.24% field efficiency. Crucially, the operator's physiological stress stayed within tolerable bounds, with a mild rise in oxygen consumption and an average heart rate increase of 60 bpm. With a payback period of only 0.86 years and a cost reduction of ₹6119 per hectare when compared to manual methods, the transplanter makes a strong economic argument for adoption. These results highlight the improved transplanter's potential to lower operating costs, lessen physical strain on farmers, and increase yield. Adoption of it might be a big step towards encouraging sustainable, mechanised rice farming in areas like Odisha and elsewhere. However, the two-row root Wash type Paddy Transplanter is only effective for small-scale mechanization and is limited by its low field capacity, need for well-prepared root-washed seedlings, and sensitivity to field conditions which should be further prioritized.

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Details of the AI usage are given below:

1. Napkin AI

**Reference**

1. Aware, V.V., Kavitkar, C.R., Patil, M.R., Shahare, P.U., Aware, S.V. and Shirsat, N.A. (2017). Physiological cost and drudgery in paddy transplanting. *Internat. J. Agric. Engg*., 10(1): 103-108
2. R Asha, K., & M Ray, B. R. (2020). Development of manual (pull-type) two-row paddy transplanter for the benefit of small farmers’ land holdings. Current Journal of Applied Science and Technology, 38(6), 1-8.
3. B. K. Behera, B. P. Varshney and A. K.Goel. 2009. Effect of Puddling on Puddled Soil Characteristics and Performance of Self-propelled Transplanter in Rice Crop. *Agricultural Engineering International: the CIGR Ejournal*, 10
4. Chandra, S., Kumar, S., & Kumar, V. (2013). Comparative performance evaluation of self propelled paddy transplanters in calcareous soil. AMA Agric. Mech. Asia Afr. Lat. Am, 44, 33-38.
5. Chaudhary V.P., B.P. Varshney and M.S. Karla. 2005. Self-propelled rice transplanter-better alternative than manual transplanting. *J. Agril. Engg. Today*, 29 (5-6): 32-45.
6. Deres, A., & Katahira, M. (2024). Performance Evaluation Of Self-propelled Rice Transplanter For Impact Study On Rice Cultivation. SAARC Journal of Agriculture, 22(1), 153-167.
7. Dewangan KN, Thomas EV and Ghosh BS. 2005. Performance evaluation of a laboratory model of rice technology. *Agricultural Engineering Today*, 29 (5-6):38-45
8. Dixit, A., Khurana, R., Singh, J., & Singh, G. (2007). Comparative performance of different paddy transplanters developed in India-A Review. Agricultural Reviews, 28(4), 262-269.
9. Ehsanullah, A. Nadeem, J. Khawar and H. Tahir. 2007. Comparison of different planting methods for optimization of plant population of fine rice in Punjab. *Pak. J. Agri. Sci*., 44(4): 597-599.
10. Ganapathi, D., & Kumar, A. S. (2015). Design, development and field evaluation of manually operated rice transplanter for system of rice intensification. International Journal of Agriculture, Environment and Biotechnology, 8(3), 735-741.
11. Garg I.K. and V. K. Sharma. 1984. Design, development and evaluation of PAU riding type engine operated paddy transplanter using mat type seedlings. Proc. ISAE. SJC, 1(2): 7- 63.
12. Garg, I., Mahal, J., & Sharma, V. (1997). Development and field evaluation of manually-operated, six-row paddy transplanter. EurekaMag. https://eurekamag.com/research/003/091/003091451.php?srsltid=AfmBOopboiKRvy0Thw\_pwZ42ALul7hZ-aL44wZVjC3-CVYs\_mggTzxiK
13. Goel AK, Behera D and Swain S. 2008.Effect of Sedimentation Period on Performance of Rice Transplanter. *Agricultural Engineering International: the CIGR Ejournal*, 10
14. *India rice area, yield and production*. (n.d.). <https://ipad.fas.usda.gov/countrysummary/Default.aspx?id=IN&crop=Rice>
15. Kannan, S. V., Veeramani, A., Hemalatha, M., Elamathi, S., Umamageswari, C., Kumar, N. S., & Rangasami, S. R. S. (2021). Suitability of Rice Transplanters and Weeders in Different Soil Types. Journal of Experimental Agriculture International, 43(4), 103–113. https://doi.org/10.9734/jeai/2021/v43i430676
16. Kavitkar C. R, Aware V.V, Patil M. R, Sahare P.U, Dhande K.G, Shirsat N.A and Aware S.V. 2017. Optimization of paddy nursery age for manual paddy transplanter. *International Journal of Agricultural Engineering*, 10(1):141-145.
17. Lohan, S. K., Narang, M. K., Javed, M., Kumar, V., Majumder, A., & Raghuvirsinh, P. (2022). Optimization and evaluation of machine–field parameters of remotely controlled two‐wheel paddy transplanter. Journal of Field Robotics, 39(6), 984-998.
18. Manikyam, N., Guru, P. K., Naik, R. K., & Diwan, P. (2020). Performance evaluation of self-propelled rice transplanter. Journal of Pharmacognosy and Phytochemistry, 9(1), 980-983.
19. Meris, P. R. V., Cruz, J. C. D., Tud, R. C., Dator, T. G. M., Dolores, J. A. J., Fragata, R. S., ... & Manuel, M. C. E. (2020, August). Design and fabrication of two-row self-propelled paddy transplanter machine. In 2020 11th IEEE Control and System Graduate Research Colloquium (ICSGRC) (pp. 173-178). IEEE.
20. Mishra, A. K., Kumar, U., & Sahu, G. (2021). Development and performance evaluation of a manually operated paddy transplanter for root-washed seedlings. Journal of Agricultural Engineering, 58(4), 323-342.
21. Mohanty, D. K., Barik K. C. and M.K. Mohanty. 2010. Comparative performance of eight-row self-propelled rice transplanter and manual transplanting at farmer’s field. *J. Agril. Engg. Today*, 34(4): 15-17.
22. Mohanty, S. K., Mishra, J. N., & Ghosal, M. K. (2012). Ergonomical evaluation of paddy transplanting operations in Odisha.
23. Pal, S., Tripathi, A., Khandai, S., & Kerketta, A. K. (2018). Design and Development the Manually Operated Root Wash Paddy Transplanter Machine. Int. J. Pure App. Biosci, 6(6), 43-47.
24. Pal, S., Tripathi, A., Khandai, S., & Kerketta, A. K. (2018). Performance evaluation and cost economics of developed manual paddy transplanter. Int. J. Current Microbiol. Appl. Sci, 7(12), 2690-2694.
25. R Asha, K., & M Ray, B. R. (2020). Development of manual (pull-type) two-row paddy transplanter for the benefit of small farmers’ land holdings. Current Journal of Applied Science and Technology, 38(6), 1-8.
26. Sebastian, S., & Thomas, E. V. (2023). Development and Performance Evaluation of a Two-row Mechanical Paddy Transplanter. Agricultural Science Digest-A Research Journal, 43(2), 164-169.
27. Shahare P. U. and Mugdha R. Bhat. 2011. Development and performance evaluation of two-row paddy transplanter. *Int. J. of Agril. Engg*., 4 (1): 103 -105.
28. Singh K.K., Sat A.A, and S.K. Sharma. 2002. Improving productivity and profitability of rice through tillage and planting management. *Japanese Society of Agricultural Science*, 75 (7): 396-399.
29. Singh, N. K., Narang, M. K., Thakur, S. S., Singh, M., Singh, S. K., & Prakash, A. (2023). Influence of transplanting techniques and age of wash root type seedlings on planting attributes of paddy rice. Cogent food & agriculture, 9(1), 2176978.
30. Yadav B. K and Kherawat B.S. Yadav, B.K. and Kherawat, B.S. (2013). Selective mechanization for enhancing productivity of rice cultivation. *Internat. J. Agric. Engg*., 6(1): 289-290.