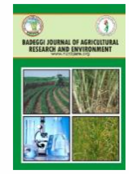
BADEGGI JOURNAL OF AGRICULTURAL RESEARCH AND ENVIRONMENT, 2026, 07(01), 18 – 31

NCRI Press

Available online: www.ncribjare.org
ISSN: 2695-2122, e-ISSN: 2695-2114
DOI: https://doi.org/10.35849/BJARE202601/217/03
Journal homepage: www.ncribjare.org



Research Article

Development and Performance Evaluation of a Wheel Actuated Four - Row Manual Rice Trans-planter

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Abstract
In order to solve the problem of high labour demand and cost of transplanting operations during rice cultivation that shares 25 % of the total production cost and requiring between 50 to 60 man – days per hectare a four-row manually-operated rice transplanter was designed, constructed and tested. The transplanter comprises of a handle, seedlings trays, a four-bar linkage mechanism, a pair of wheel drive and a float. The results of machine evaluation parameters show that age of seedling, angle of inclination of seedling tray and depth of transplanting have significant effect at $p < 0.001$ on transplanting efficiency, floating hills, missing hills and germination count. The machine effectively transplanted seedlings in four rows with inter – row spacing of 250 mm. its effective field capacity was 0.17 ha/h at an operating speed of 1.1 m/s.

Keywords: Field capacity, Nursery, Design, Rice seedlings, and Transplanter.

Introduction

Rice (*Oryza sativa*) is one of the three most important food crop in the world which forms the staple diet of 2.7 billion people (Muhammed *et al.,* 2019). It is grown in almost all the part of the world except Antarctica. In the year 2022 the total production stands at 515 million tonnes worldwide. Asia alone produces up to 500 million tonnes. Its cultivation is of immense improvement to food security of Asia, where more than 90% of the global rice is produced and consumed (Bala and Wan - Ishak, 2014). Statistically, India is ranked first in area under paddy (41.66 million ha) and second in terms of production (85.31 million tonnes) (FAO, 2022) and it stood next only to China in the world with respect to rice production. In 2021, rice production in Nigeria amounted to 8.3 million metric tons making the country the largest producer in Africa. Egypt and Madagascar followed with an output of about 4.8 million and 4.4 million metric tons of rice, respectively (Saleh, 2023). Rice remains the staple crop consumed in Nigeria in a large volume per annum and the estimated consumption stands at 5 million metric tons of milled rice while annual consumption per capita stands at 29 kg and this has continued to rise at 11 % per annum due to population and income growth (Onyegbulam *et al., 2018*).

Transplanting which is the act of uprooting rice seedlings from nursery bed and planting it on the main field is one of the labour consuming operations during rice cultivation that shares 25 % of the total production cost (Kumbhar *et al.*, 2017). The man days required for transplanting ranges from 50 - 60 man-days/ha, although during the time of planting operation, labour can be very scarce and costly; the farmers have to meet up with appropriate time hence, the transplanting

Received on 6th February, 2025; Revised 21st March, 2025; Accepted 28th March, 2025 and Published on 1st August, 2026

operation needs to be mechanized. Rice transplanters were first developed in Japan in 1960s, whereas the earliest attempt to mechanize rice transplanting dates back to late 19th century. In Japan, development and spread of rice transplanters progressed rapidly during the 1970s and 1980s (Kumbhar *et al.*, 2017).

Transplanting machines have been under development for years by different researchers improving performance, components functions, and simplifying mechanism. Mainly two types of rice transplanter exist: riding type and walking type. Riding type is power driven and can usually transplant six lines in one pass. On the other hand, walking type is manually driven and can usually transplant four lines in one pass (Anoop *et al.,* 2007; FAO, 2022). Table 1 shows the summary of literature on the development of manual transplanters.

A common rice transplanter comprises: a seedling tray like a shed roof on which mat type rice nursery is set; a seedling tray shifter that shifts the seedling tray like a carriage of typewriters; and plural pickup forks that pick up a seedling from mat type nursery on the seedling tray and put the seedling into the earth, as if the seedling were taken between human fingers (Ganapathi and SurendraKumar, 2015,).

Mechanized transplanting offers significant advantages including increased efficiency, reduced seedling damage and improved crop uniformity. Among the available solutions wheel actuated manual rice transplanters serve as a cost effective and practical alternative for small and medium scale farmers who may not afford fully automated machines. This machine utilized a wheel driven mechanism to automate the seedling placement process while maintaining manual control.

The study focuses on the development of a four – row wheel- actuated rice transplanter designed to improve transplanting efficiency while keeping operational costs low as well as its performance evaluation.

Materials and Methods

The bio-materials

The bio material used in this study was a viable rice seed of FARO 44. This variety was sourced from National Cereals Research Institute, Badeggi.

Construction materials

The list of materials and specifications needed for the construction of the rice transplanter are given in Table 2.

Determination of physical and mechanical properties of seedlings

For the construction of this machine, some physical and mechanical properties of rice seedlings were determined. These properties include, (stem diameter, height, weight, angle of friction, hardness, tensile strength and compressive strength). One kilogram (1kg) of rice (FARO 44) was obtained from rice research programme of the National Cereals Research Institute (NCRI), Badeggi which was used for establishment of nursery (50 X 50cm) on the rice research field of NCRI on 23rd September, 2021. After 3 weeks of growth and development (23rd September, 2021 – 17th October, 2021) samples of the seedlings were used to determine each of the physical and mechanical properties needed.

Determination of physical properties

Stem diameter

The thickness of the stem was measured following the method prescribed by the American standard for nursery stock (ASNS, 2014) with the aid of a digital Venier calliper (with part no: 303 -101, measuring range of 0 – 25 mm and accuracy of 0.01 mm), the middle portion of the stem of each of the seedling was placed between the anvil and the spindle of the Venier calliper and the stem thickness was read on the calibration on the sleeve and the thimble.

Height

The measurement of seedling height of each of the sample was carried out following the method prescribed by the ASNS (2014) with little modification where the seedlings were laid on a table and the distance from the tip of the seedling to the end of its root was measure using a flexible

Ningbo tape having an accuracy of 1 mm.

Weight

A 1000-unit mass refers to the mass of thousand seedlings. The mass and density characteristics of the seedlings are quite useful in estimating product yield and machine throughput of equipment. Also, seedlings weight affects seedling flow and in turn, influences the design of seedling tray for seedlings in transplanters (Frances, 2012). The seedling's weight was determined by placing it on an electronic balance which has an accuracy of 0.01 grams from where the weight of the seedling is read off, this was done for all 100 samples used

Angle of friction

To determine the static coefficient of friction (µ) for materials like plywood, mild steel, and plastic, a method described by Orhevba *et al*. (2013) was used. In the experiment, a Formica box with dimensions 150mm x 100mm x 40mm, open at the top and bottom, was filled with rice seedlings. This box was placed on an adjustable tilting surface. The surface was slowly angled upward until the box started to slide. The tilt angle at this point was noted using a scale.
the coefficient of friction was calculated using Equation 1:

$$\mu = \tan \emptyset \quad (1)$$

Where: µ is the coefficient of friction
∅ is the angle of friction (degree).

Determining hardness

To measure the hardness of seedlings, a Penetrometer (Type 6402, Model 32887) was employed, following the guidelines by Oje and Ugbor (1991). The device's top part was carefully screwed down to make contact with the sample surfaces. The hardness of a seedling is indicated on the device when the first sound is heard, signifying the pressure applied. The recorded hardness value is then divided by the contact area to calculate the contact hardness number.

Determination of compressive Strength

This determines the ability of seedlings to withstand squeezing forces during transplantation. A Universal Testing Machine (UTM) in compression mode was used. Some segment of seedling stem was placed vertically between the compression's plates. Gradual downward force was applied until deformation was observed and the force was recorded; the compressive strength was then computed using Equation 2:

$$\text{Compressive strength} = \frac{force\ at\ failure}{cross-sectional\ area}, \frac{N}{m^2} \quad (2)$$

Determination of tensile strength

This is measure of how much force the seedling can withstand before breaking, it is necessary to ensure that seedlings do not break when pulled or held by transplanting claws. A Universal Testing Machine (UTM) with tensile grips was used. The setup was such that tensile fixture with soft clamps with load range of 1 – 50n and speed of 1 – 10 mm/min was used to avoid premature breakage.

Design considerations

i. The following factors were considered in the design specifications of the machine.
ii. Engineering properties of rice seedlings
iii. Age of the seedlings (21 -25 days) ((Muhammad, 2016).
iv. Average power human being can generate (100 W) (Ibrahim *et al., 2019*).
v. Average speed of an adult = 1.1 m/s (Fermando *et al.,* 2020)
vi. Availability of materials
vii. Strength of the materials
viii. Ease of operation.
ix. Ease of maintenance
x. Material Cost.

Theoretical field capacity of the transplanter (TFC)

Designing a transplanter that can give a theoretical field capacity of 0.3 ha/ hr at a working width of 0.75 m, the average speed of the machine was calculated using Equation 3 (Abubakar *et al.,* 2019).

$$TFC = WS/10 \quad (3)$$

Where:
TFC = theoretical field capacity
W = working width of the transplanter, 0.75 m
S = working speed of the machine, 1.1 m/s

(Fermando *et al., 2020).*

$$S = \frac{TFC}{W} \quad (4)$$

Therefore S = 1.1 m/ s
Since average human walking capacity is 1.1/hr which is equal to the speed required to achieve the targeted field capacity of 1.1 m/s, it means that this field capacity can be achieved.

Positioning of seedling tray
The tray's main purpose is to hold and guide seedlings to the transplanting arm. It was designed considering factors like width, length, angle, and forward speed. Four trays are used side by side to plant four rows at once. The amount picked up by the planting finger each time determines how the tray moves with each stroke of the planting arm. To keep seedlings moving to the transplanting arm, trays are tilted between 25° and 50° to let gravity help seedlings slide down (Figure 3.2). A moderate angle needs less energy to move the seed mat, while a steep angle can cause seedlings to fall and bunch up at the tray's end, making transplanting harder (Karthik *et al.,* 2018).

Design of planting fingers
The transplanting fingers were made up of four bar linkage mechanism with appropriate link length and link angles (Table 3). Figure 1shows basic four bar linkage of four bar linkage mechanism.

***Rate of oscillation*: The rate oscillation of the planting fingers or mechanism is equivalent to the rotational speed of the driven sprocket powering it and is given in Equation 6 (Khurmi and Gupta, 2005).

$$N_p = N_2 \times S_R \quad (6)$$

Where:
N_p= Rate of oscillation of planting fingers, rpm.
N_2 = speed of the driven sprocket, rpm
and S_R = Sprocket velocity ratio

Determination of number of hills transplanted per minute
The number of hills per minute by the machine was calculated using Equation 5

$N_h = Np \times N_R$ (*Kumar et al.,* 2009). (7)

Where,
Np = No. of oscillation per minute and
N_R = No. of rows

Circumference of imaginary circle formed by picking fingers

$$D_S = \frac{C}{S_R} \quad (8)$$

Where, D_S = intra row spacing, 250 mm; C = Circumference of the imaginary circle formed by picking fingers, mm; S_R = Sprocket velocity ratio (Nitesh, 2021).

Design of wheel drive
The drive wheel was designed and constructed to support machine weight and increase traction. Fins were provided on the periphery of the wheel to help develop better traction and grip on the soil. The transplanter was provided with two drive wheels which can be pulled by a single person while maintaining a hill-to-hill distance of 25 cm with aid of chain and sprockets having 48 and 18 number of teeth respectively. The gear thus obtained was found to be 8:3. Based on the obtained gear ratio and following parameters the drive wheel dimension was determined (Samal, 2019).

Assuming, hill to hill distance = 25 cm and sprocket velocity ratio of 3.2 as obtained from equation 5. Let, D be the diameter of the wheel in meters, then:

Distance travelled in a single revolution of the drive wheel = πD_W (9)

Also, Distance covered in one revolution = hill spacing x velocity ratio (10)

Hill spacing x velocty ratio = πD_W (Samal, 2019) (11)

The effective diameter of the drive wheel ≈ 25.45cm (0.255 m) or $r_W = 0.1275\ m$

Angular speed of the wheel drive

The angular speed of the wheel drive was calculated from the Equation 12

$$\omega_W = \frac{V_W}{r_W} \tag{12}$$

Where:
$\omega_W = angular\ speed\ of\ the\ wheel\ drive, rad/s$
$V_W = velocity\ of\ the\ wheel\ drive, 1.1\ m/s$ (Assumed).

$r_W = radius\ of\ wheel\ drive, 0.1275\ m\ from\ Equation\ 9$ and the revolution per minute of the wheel (N_W) was calculated using Equation 13

$$N_W = \frac{60\omega_W}{2\pi} \tag{13}$$

Figure 5 show the isometric view of the ground wheel.

Determination of weight of transplanter

The total weight of a machine is calculated considering the length, geometric sections and mass perunit length of individual component materials used and the weight of various metals used was computed from Equation 14 (Artizono, 2017).

Total Weight = Weight of frame + weight of seed tray + weight of wheel assembly + weight of handle + weight of accessories + weight of iron board + weight of rice seedlings.

$$W_T = W_c + W_{st} + W_h + W_{tw} + W_p + W_a + W_f + W_s \tag{14}$$

Where:
W_T= total weight of the machine, N.
W_c = weight of the chassis.
W_{st}= weight of seed tray.
W_w = weight of wheel assembly.
W_a= weight of other accessories.
W_f = weight of iron board (float).
W_h = weight of handle.
W_s = weight of rice seedlings.
W_{pf} = weight of planting fingers.

Determination of draft of the rice transplanter

The draft of the transplanter is going to be of two components which are from the weight of transplanter and frictional loses on the bearings and transplanting mechanism. The following relation in Equation 15 was used (Kavin *et al.*, 2017; Ibrahim *et al.,* 2019; Sakai and Araya, 2018).

$$D = (K \times A_c) + (M_T \times S) \tag{15}$$

Where:
$D = draft, N$
$K = soil\ resistance\ coefficient\ on\ clay\ soil = 10{,}000\ \frac{N}{m^2}\ (\text{ASABE}, 2015)$

$A = contact\ area\ of\ the\ the\ transplanter, m^2$
$M = mass\ of\ the\ transplanter = 75.8\ kg$ (From Equation 14)
$S = velocity\ of\ pulling\ force = 1.1\frac{m}{s}$ (Fermando, 2020)

But the contact area (A) of the transplanter was calculated using Equation 16.

$$A_c = W_e \times t_d \tag{16}$$

Where:
$A_c = contact\ area, m^2$,
$W_e = effective\ width\ of\ the\ transplanter, 0.75\ m$
$t_d = depth\ of\ penetration, 0.05\ m,$ then the contact area became

Power requirement of the machine (P_m)

Since the transplanter was manually operated the serve as the power provider and using Equation 17, the power requirement was calculated.

$$P_m = D \times S \tag{17}$$

Where P_m = power, W,
D = draft = 412.9 N and
S = forward speed of the transplanter.

Design of the main shaft

The shaft is used to transmit torque from the ground wheel to four bar linkage system by means of chain drive. The torsion equation based on shear stress theory was used (Khurmi and Gupta 2005), since the shaft is subjected to twisting moment only.

$$d = \sqrt[3]{\frac{16T}{\pi \times \tau}} \quad (18)$$

also

$$T = \frac{60P_m}{2\pi N} \quad (19)$$

Where:

$\tau = permissible\ shear\ stress\ 40\frac{N}{mm^2} for\ mild\ steel$ (Khurmi and Gupta, 2005)

$d_s = diameter\ of\ shaft, mm$

$T = torque = 51.8740\ Nm$

$P_m = power\ to\ be\ transmitted\ by\ the\ shaft = 454.19\ W$

$N = revolution\ per\ minute\ of\ the\ wheel = 38$

$d_s = 18.76\ mm$

Therefore, a commercial shaft of 20 mm is hereby selected.

Construction and principle of operation of the rice transplanter

To make rice planting more efficient and less labour – intensive, a manually operated four-row transplanter was designed. This machine was specifically built to transplant washed root – type seedlings using wheel actuated mechanism. It consists of key components such as transplanting unit, seedling trays, a float and a power transmitting system. At the heart of transplanting unit is a carefully designed mechanism that includes cranks, coupler link, follower link, finger, and a sturdy frame to support the planting process. The crank was the driving force behind the system. With four cranks working together to ensure smooth operation. The distance between crank shaft and crank pin was set at 100 mm for optimal performance. Additionally, four follower links and four coupler links, each measuring 198 mm in length play a crucial role in the mechanism. To hold the planting fingers in the correct position, a coupler extension was crafted using mild steel flat bar (25 mm × 5 mm). one end of this extension was securely welded to a coupler bush at fixed angle of 109°, while the other end was designed to hold finger in place. The machine uses four fixed fork-type fingers also made from mild steel flat bar, to grip and plant the seedlings. To ensure a firm hold on each seedling, a notch (10 mm width and 30 mm depth) is cut out in the tip of each finger. The other side of the finger is designed to be adjustable, allowing it to be tightened at right angle for efficient planting.

The float was designed based on row- to-row spacing and number of rows used in the rice transplanter.it helps prevent sinking and facilitate smooth movement in the muddy field. The front parts of channels were inclined at approximately 45° to prevent mud from entering during operation.

The seedling tray, rectangular in shape, was made from 18-gauge thick mild steel sheet. four seedling trays were constructed, each measuring 230 mm in width and 520 mm in length. These trays were separated into components by ribs measuring 30 mm in hight and 1.5 mm in thickness. The trays were set at a 30° inclination with the horizontal and secured with an elastic rubber strip to prevent the seedlings falling out during loading and operation.

This pull-type transplanter is designed to plant washed root seedlings in four rows per pass. It features rectangular handle for pulling. The Power generated at the transplanter wheel is transmitted to the transplanting mechanism's finger using a chain and sprockets system.Two sprockets are employed for power transmission, with gear ratio of 3: 1 ratio, meaning one wheel shaft rotation will result in three crank wheel rotation. As the operator pull the handle, the fingers move through the seedling tray slot and takes a small cluster of seedlings and insert them into the puddled soil at a depth of 20 mm- 70 mm. After transplanting the seedlings in the puddled soil, the fingers returned back to their original positions after transplanting the seedlings. Figures 2, 3 and 4 show the Isometric, orthographic and pictorial views of the constructed transplanter.

the operator pushes the transplanter forward, the wheel rotates and provides input motion to the mechanism, this motion is transmitted to the input crank of the four-bar linkage causing the gripper arms to oscillate in a precise and repetitive pattern. The picking arm moves towards the seedlings tray, grabs the required number of seedlings and hold them, the linkage mechanism moves the picking arm downward into the soil, ensuring the seedlings are inserted to the soil at the correct depth and at the lowest point of the picking finger movement, the seedlings are automatically released into the soil. Finally, the four-bar linkage lifts the picking finger arm back to the starting position ready to pick next seedlings ensuring uniform intra row spacing making the process efficient.

Performance evaluation parameters

To evaluate the machine's effectiveness, key performance indicators such as field missing hills, plant damage, floating hills, planting depth and seed placement accuracy were measured.

Percentage missing hills

This is the ratio of the total number of hills without seedlings to the total number of hills expressed in percentage, calculating using equation 22 (Mohammed *et al.*, 2019).

$$M_H = \frac{M_{th}}{H} \quad (21)$$

Where;
M_H = missing hills, %
M_{th} = total number of missing hills in sample area
H = total number of hills

Percentage plant damage

This is the ratio of total number of plants damaged in hills after transplanting to the total number of plants transplanted in a sample space expressed in percentage. This will be calculated using equation 23 (Mohammed *et al* 2019; Rajib *et al., 2015*).

$$P_{pd} = \frac{P_d}{TP_d} \quad (22)$$

Where;
P_{pd} = percentage plant damaged, %
P_d = total number of plant damage in a sample area and
TP_d = total number of plants transplanted in sample area.

Percentage floating hills

It is the ratio of the total number of hills floating after transplanting to the total number of hills expressed in percentage and it can be calculated by equation 24 (Murali *et al.,* 2016).

$$P_{FH} = \frac{FH}{T_{FH}} \quad (23)$$

Where:
P_{FH}= Percent floating hills, %
FH = number of floating hills in a sample area
T_{FH}= Total number of hills in sample area

Depth of planting, cm

This is the depth of root zone after transplanting in a given sample area, measured in centimetres.

Hill to hill spacing, cm

This is the length of space between one successive hill and other in a sample area, measured in centimetres.

Number of plants per hill

This is the count of number of plants in each hill in a given sample area.

Percentage buried hills

It is the ratio of the number of buried hills after transplanting to the total number of hills expressed in percentage. Buried hills will be calculated by equation 25 (Murali *et al.,* 2016).

$$P_{BH} = \frac{BH}{T_{NH}} \quad (24)$$

Where;
P_{BH}= Percent buried hills, %
BH = number of buried hills
T_{NH} = Total number of hills transplanted

Results and Discussion

Physical properties of the rice seedlings

The results of physical properties of the seedlings are presented in table 4. From the table the maximum and minimum values for length were 250 mm and 145 mm respectively given an average value of 211.18 mm. the standard deviation of 30.02 suggest a moderate spread in seedling length around the mean. The coefficient of variation of rice (CV) of 14% (0.14) indicates relatively variability in seedling length. The length of the seedlings was needed in design of seedling tray. When compare with wheat seedlings of the same age (Baset *et al.,* 2010) (100 – 180 mm) it is apparent that rice grew taller than wheat but the higher (CV) (18=25%) in wheat indicates greater variability in seedling height compare to rice.

The weight of seedlings (Table 4) varied from 0.8 g to 1.5 g with an average weight of 1.15 g. A CV of (0.17 or 17 %) this is slightly higher than that of length suggesting greater variability in weight. The seedling holding and release mechanism must handle seedling weight without damaging delicate root or leave. Rice seedling weighs less (0.8 – 1.5 g) when compare to wheat (1.5 = 3.5 g) (Baset *et al.,* 2010).

The stem diameter ranged between 0.66 mm and 1.76 mm; with an average of 1.11 mm. the standard deviation of 0.88 mm suggests a high degree of variation. The coefficient of variation (0.79 or 79 %) is the highest of the three parameters, indicating inconsistency in stem thickness therefore the gripping jaws or holding mechanism must adjust for high variability in rice stem thickness.

Hardness

The hardness also increases with age of seedlings, indicating stronger cell wall development (Table 4), The hardness of rice seedlings at 21 days after planting was in the range of 3.5 – 5.0 N with an average of 4.25 N, This is an indication that the transplanter should be capable of handling varying hardness levels without damaging the seedlings.

Tensile strength

From table 4 the result of tensile strength ranges between 2.0 – 3.5 MPa at 21 days after planting which is within the acceptable limit. It is evident from the results that tensile strength increases with age but the rate may slow down. A higher tensile strength means seedlings are likely to break when pulled.

Compressive strength

The values of Compressive strength increase over time due to stronger stem and varied from 1.0 – 1.6 (1.3) MPa at 21 days after planting (Table 4). This implies that the transplanter should apply optimal insertion force to push seedlings into the soil without causing excessive stress.

Machine evaluation parameters

The developed four-row manually operated rice transplanter was tested under puddle field condition. The machine successfully transplanted 500 hills in a 5 m × 5 m plot using 21- day old FARO 44 seedlings. The performance results are summarized in table 5.

Effective field capacity and efficiency

The effective capacity of the transplanter was 0.2 hectare per hour (ha/h). this means a farmer could cover about 2000 m^2 per hour making it a time saving alternative to traditional manual transplanting. The overall transplanting efficiency was 65% which is within the expected range. The machine worked at an average operating speed of 0.5 m/s. The transplanter successfully transplanted 4 rows of seedlings at 250 mm inter-row spacing. Average missing hills, visible damage and floating hills were 10 %, 9 % and 8 % respectively. It was found that 9.0 per cent of hills had damaged seedlings during operation but after a week they recovered and resembled healthy hills. These results were similar to the results gotten by Nirala and Kumar (2020) who got (9%, 4% and 6 %) for missing hills, visible damage and floating hoills . it was also observed that floating hills occured where the height of standing water was more due to uneven field. This might be as a result of inability of soil to retain the seedlings. The average depth of planting was found to be 5.5 mm. The depth of planting varied from 20 mm to 90 mm which is in the acceptable range. Variations in depth have been occurred only on small depressions/ ditches made by the foot of the operator in the field.

The average hill- to-hill spacing was found to be 200.25 mm, A speed of 0.5 m/s was maintained by the operator. Thus, variation from 200 mm to 250 mm was observed. However, sometimes the variation noticed in hill-to-hill spacing might be due to improper pulling of the operator. Variation in number of seedlings per hill was also observed, this is within the range 2 to 9 this might be due to the entanglement of roots and uneven seedling growth, The number of seedlings per hill was found to be 3.91, 3.978 and 4.295 for 20 days, 25 days and 30 days old seedlings, respectively. The average number of seedlings per hill was 5.5 (sometimes varied from 2 - 9) which is in the acceptable range but higher than the recommended (2 - 3 seedlings per hill). It depends on the cross-sectional area of the stem of the seedlings and the opening of the transplanting finger slot. The hills fixed by transplanter stood at an angle of 60 to 80 degree that became straight after 4-5 days of transplanting. A few times, clogging of transplanting fingers with seedlings was also observed due to buckling of seedlings at the base of the seedling tray. It had also been observed that hill-to-hill spacing was wider at some places and narrower at others resulting in deviation from the desired spacing. It might be due the fact that there were variations in length of pull by the operator. These results are in agreement with the findings of Kumar and Thomas (2019); Nirali and Kumar (2020).

Conclusion

The manually operated four row rice transplanters proved to be a practical and effective solution for smallholder farmers. The developed rice transplanter transplanted root washed type seedlings on 4 rows at 250 mm inter-row spacing. Effective field capacity of the manually operated rice transplanter was 0.2 ha/h at an operating speed of 0.5 m/s. Percentage missing hills, visible damage of the seedlings by the transplanter and floating hills were 10 %, 9 % and 8 % respectively.

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Table 1: Summary of literature on the development of manual transplanters

Authors	Title	Major findings	Impact
Umar *et al*.,2001	Evaluation of diffusion possibilities of mechanical transplanting method	Evaluated the economic viability of mechanical transplanting methods. Although more expensive than traditional method, higher plant density resulted in increased profitability though concerns about labour displacement were noted.	Provided economic analysis of mechanical transplanting, highlighting both the profitability and the socio-economic consideration of adoption.
Shinde *et al*.,2018	Review paper on development of rice transplanter	Presented a review on the development of manual rice transplanters, highlighting the labour-intensive nature of traditional methods and benefits of mechanization In reducing labour costs and increasing efficiency.	Reinforced the need for developing manual transplanters to alleviate labour challenges, guiding future research and development efforts.
Kumbhar *et al*.,2017	Design analysis and fabrication of manual rice transplanter.	Analysed and fabricated a manual rice transplanter, focusing on reducing labour requirements and increasing planting efficiency. The transplanter was designed to be light weight and cost effective, making it accessible to poorer farmers.	Enhanced the feasibility of mechanization for small-scale farmers by developing an affordable and efficient manual transplanter, encouraging wider adoption.
Nirala and Kumar, 2020	Development of a manually operated rice transplanter using four bar linkage mechanism	Developed a manually operated two=row rice transplanter utilizing a four-bar linkage mechanism. Achieved an effective field capacity of 0.012 ha/h at an operating speed of 0.36 km/h. the transplanter reduced the cost by 43%	Provided a cost-effective solution for small-scale farmers, reducing labour costs and increasing transplanting efficiency.

Table 2: Machine construction materials

Description	Quantity	Type of material required	Specification	Material	Machining process
Picking Arm 1	4	Flat bar	25mm * 5mm * 80mm	Mild Steel	Drilling
Picking Arm 2	4	Flat bar	25mm * 5mm * 180mm	Mild Steel	Drilling
Picking Arm 3	4	Sheet	5mm * 200mm * 140mm	Mild Steel	Drilling, Cutting
Picking Arm Shaft 1.0	8	Rod	12.7mm Dia * 25mm	Mild Steel	Drilling
Picking Mechanism Coupler	4	Rod	35mm Dia * 25mm	Mild Steel	Lathe
Picking Mechanism Shaft 2	2	Rod	12.7mm Dia * 150mm	Mild Steel	Drilling
Picking Mechanism Support Angle 1	12	Angle iron	25mm * 25mm * 3mm	Mild Steel	Drilling
Picking Mechanism Supporting Wall	4	Sheet	135mm * 180mm * 5mm	Mild Steel	Drilling, Cutting
Picking Mechanism Support Angle 1	12	Angle iron	25mm * 25mm * 3mm	Mild Steel	Drilling
Picking Mechanism Shaft 1	2	Rod	12.7mm Dia * 230mm	Mild Steel	Drilling

Table 3: Kinematic links dimensions of the transplanting mechanism

Parameters	Dimensions
Length of coupler link	198 mm
Length of follower link	300 mm
Length of fixed link	320 mm
Distance from coupler link centre to tip of finger	400 mm
Angle of the Fixed link	300°
Angle of the coupler link with the tip of the finger	170°

Table Error! No text of specified style in document.**: Results of Physical and Mechanical Properties of FARO 44 Rice Seedlings at at 21 days after planting**

Property	Maximum	Minimum	Average
Seedling height, cm	16.0	20.0	18.0
Stem diameter, mm	1.5	2.0	1.8
Fresh weight, g	1.2	1.8	1.5
Hardness, N	3.5	5.0	4.3
Tensile strength, MPa	2.0	3.5	2.8
Compressive strength, MPa	1.0	1.6	1.3

Table 5: results of performance evaluation parameters

S/N	Parameter	Observed value
1	Effective field capacity	0.2 ha/h
2	Percentage missing hills, %	10
3	Percentage plant damage, %	9
4	Percentage floating hill, %	8
5	Depth of transplanting	2 – 9 mm (5.5)
6	Average hill to hill spacing	200 – 250 mm (225)
7	Number of seedlings per hill	2 – 8 (5)
8	Percentage buried hill, %	7
9	Transplanting efficiency, %	65

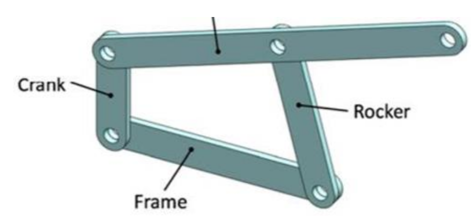

Figure 1: Four Bar Linkage Mechanism

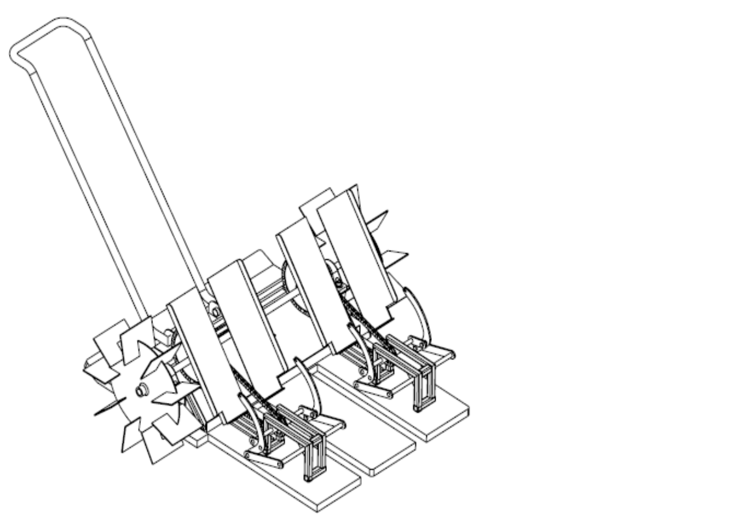

Figure 2: Isometric View of Rice Transplanter

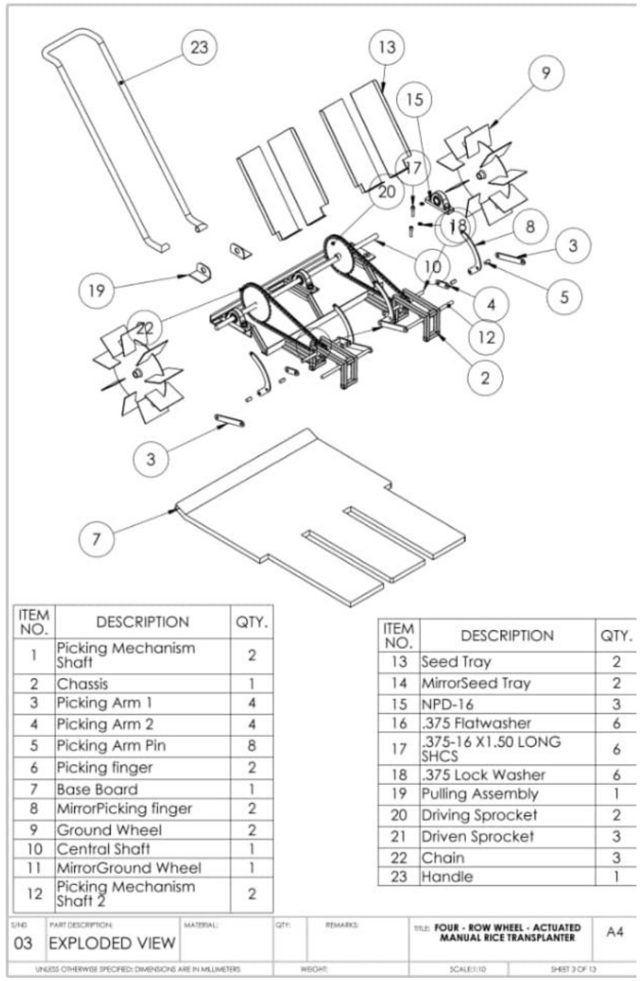

Figure 3: Exploded View of the Transplanter

Figure 4: Pictorial View of the Transplanter