Nigerian Journal of Engineering Science Research (NIJESR).
Copyright@ Department of Mechanical Engineering, Gen. Abdusalami Abubakar College of Engineering, Igbinedion University, Okada, Edo State, Nigeria.
ISSN: 2636-7114
Journal Homepage: https://nijesr.iuokada.edu.ng/

Development and Performance Evaluation of a Manually Operated Two-Row Rice Transplanter

[1a]Nadungu, G., [2b]Saleh, A., [3c]Ogijo, S., [2d]Mohammed, U.S., [4e]Musa, B.A.

[1] *Federal Ministry of Agriculture & Food Security, Abuja*
[a]*gagarenadungu@yahoo.cm*
[2*]*Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria, Nigeria*
[b]*salehaminu@gmail.com*
[3]*National Seed Service, Zaria*
[c]*samuelogijo@yahoo.com*
[4d]*Federal Polytechnic, Nasarawa, Nasarawa State, Nigeria*
[e]*babaadamum50@gmail.com*

**Corresponding Author: Saleh, A.; salehaminu@gmail.com*

Manuscript History
Received:19/04/2024
Revised: 10/06/2024
Accepted: 22/06/2024
Published: 30/06/2024
https://doi.org/10.5281/zenodo.17286609

Abstract: *This study presents the design, fabrication, and evaluation of a manually operated two-row rice transplanter in order to enhance the efficiency for smallholder rice farmers by reducing the labour intensity, ensures uniform and accurate seedling placement. Major components of the transplanter include the main frame, crank handle, seedling trays, feeding mechanism, chain and sprocket transmission, cams, and planting arms. Performance evaluation was conducted to assess the effects of operational speed, rice variety, and seedling age on transplanting efficiency (TE), effective field capacity (EFC), percentage of floating hills (PFH), percentage of missing hills (PMH), and establishment rate (Er). A 3×2×2 factorial experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications under puddled field conditions. Treatments included three operational speeds (0.3, 0.45, and 0.6 m/s), two rice varieties (FARO 44 and FARO 52), and two seedling ages (14 and 21 days). Materials of various sizes were selected for different components of the transplanter based on availability, strength, and durability. Galvanized metal sheet (1 mm thick) was chosen for constructing the floating base and seedling tray. Since the floating base and seedling trays was primarily wet, they require a lightweight material with anti-rust properties. The frame was constructed from mild steel hollow square pipes, while the operator handle was made from a mild steel hollow pipe. The choice of mild steel is due to its comparatively low cost compared to galvanized steel. The cam and camshaft were all made from mild steel because of its availability, low cost, and ductility. The results indicate that the machine is suitable for small-scale rice production, offering a cost-effective and labour-saving alternative to traditional manual transplanting.*

Keywords: Evaluation, Labour Intensive, Manually Operated, Rice, Transplanter

INTRODUCTION

Rice (*Oryza sativa*) is one of the staple crops grown in Nigeria and the most widely consumed crop in the country (Akpokodje *et al.,* 2001). Over one billion people worldwide are engaged in rice cultivation, and more than three and a half billion people rely on rice as a primary food source to meet their daily needs (Pimpalgaonkar *et al.,* 2020). Due to the world population's dependence on rice, it is crucial to implement efficient methods that will increase rice yields as much as possible, Rajivir *et al.,* (2007). Rice is a labour-intensive crop that requires approximately 850-900 man-hours for the cultivation of one hectare. Singh *et al.* (2012) reported that high labour requirements during peak periods increase the cost and labour for rice cultivation. Transplanting is a very important pre-harvest operation carried out by establishing already uprooted seedlings raised from the nursery in an already prepared field. It is a very tedious and labor-intensive operation that accounts for more than 25 % of the total working hours in rice production. This operation, if carried out on time, gives the plant a competitive edge over weeds and leads to an increase in crop yield. Manual transplanting is a tedious and time-consuming operation that requires many labourers for execution. Chaudhary *et al.* (2021) reported that manual transplanting is a tedious and time-consuming operation that requires about 250-300 man-hours per hectare. Adopting the use of mechanization in rice production, with transplanting being a major operation in the rice production value chain, could lead to an expansion of paddy production fields and an increase in sectoral productivity.

The Nigerian rice production sector is dominated by peasant farmers who hold less than two hectares and perform their farming operations manually, resulting in low capacity and productivity, Tupkar *et al.* (2020). Most of these farmers are unaware of the existence of rice transplanters, as these transplanters are not commonly used in the country. The capacities, cost, and accessibility of these imported rice transplanters made them unsuitable for application in Nigeria, where small-scale rice production dominates the country's rice sector. Nigeria's national rice demand, estimated at approximately 7.4 million metric tons annually, significantly outpaces its domestic production of about 5.2 million metric tons, resulting in a demand gap of roughly 2.2 million metric tons, Sultan *et al.* (2018). This shortfall positions Nigeria as a net importer of rice, compelling successive administrations to prioritize increasing local rice production. The focus on boosting domestic output aims to reduce the country's substantial food import bill and achieve national food security. Hence, there is the need to introduce a mechanically operated rice transplanter that is locally developed, cheap, easy to operate as well as reduce the drudgery experienced by the farmers in rice transplanting operation. This could lead to expansion of paddy fields as well as reduce the cost of rice production while increasing yield and productivity of the farmers.

MATERIALS AND METHODS

2.1 **Material Selection**

Materials of various sizes were selected for different components of the transplanter based on availability, strength, and durability. A galvanized metal sheet (1 mm thick) was chosen for constructing the floating base and seedling tray. Since the floating base and seedling trays was primarily wet, they require a lightweight material with anti-rust properties. The frame was constructed from mild steel hollow square pipes, while the operator handle was made from a mild steel hollow pipe. The choice of mild steel is due to its comparatively low cost compared to galvanized steel. The cam and camshaft were all made from mild steel because of its availability, low cost, and ductility.

2.2 Selection of Rice Varieties

2.2.1 Selection Criteria

The varieties of seedlings chosen were based on their strong yield potential, disease resistance, excellent eating quality, high milling yield, and market suitability. The FARO 44 variety exhibits unique characteristics, including early maturity (110–120 days), which is achieved sooner than that of traditional varieties, higher yields, tolerance to specific stresses, blast resistance, and long grains (Vasudeva *et al.*, 2014; Durga *et al.*, 2020) recommends FARO 44 (Sippi 692033) and FARO 52 (WITA–4) based on clear evidence of high yield.

2.2.2 Conceptual Design of the Rice Transplanter

The conceptual design of the manually operated rice transplanter is a walk-behind machine tailored for smallholder paddy fields. The transplanter is manually driven via a hand-operated crank attached to the camshaft. This design aims to enhance planting efficiency while minimizing the drudgery and time associated with manual transplanting. The transplanter is composed of several essential components: a mild steel frame (chassis), seedling tray holders, planting arms, a camshaft, and a fork-bar planting mechanism. The planting mechanism uses a double-arm fork that pivots to grasp and deliver seedlings

Nadungu *et al.*, (2024). Development and Performance Evaluation of a Manually Operated Two-Row Rice Transplanter. *Nigeria Journal of Engineering Science Research (NIJESR)*, 7(1): 103-115. https://doi.org/10.5281/zenodo.17286609

into the soil, swinging at an angular displacement of approximately 39° to achieve a planting depth of up to 50 mm. The assembly is mounted on a floating frame with a treated hardwood base (0.525 m × 0.802 m) for buoyancy and stability. The seedling trays are positioned above the planting assembly at a 60° angle to facilitate gravity-assisted feeding.

2.2.3 Seedling Tray Design

The development of seedling holders involves designing their height and inclination. Height is a parameter related to the area, while inclination pertains to crop characteristics. The inclination facilitates the flow of seedlings at the desired speed to maintain a consistent population in the hills. The holder is positioned 15 cm above the ground to allow for easy placement of seedlings without any loss (Yanmar, 2016). Seedlings should be placed horizontally, with preferred young seedlings being approximately 20 days old to suit the operation (Pasuquin *et al.*, 2008). The tray is designed to carry the seedlings and direct the plants to the transplanting arms. Key factors such as width, length, angle, and speed of movement were considered in the design of the tray mechanism (Rickman *et al.*, 2015). Since two plant rows are planted simultaneously, two trays are positioned side by side for each transplanting arm. To ensure a constant feed of the seed mat to the transplanting arms, it should rely on gravity to descend to the end of the tray; this is accomplished by periodically wetting the tray surface. An excessive angle impacts the descent and compaction of the nursery at the end of the tray, making it difficult for the transplanting arms to retrieve the plants. The final angle of the tray is set at 60° (Singh, 2018).

2.3 Machine Description and Components

The developed 2-row, manually operated rice transplanter is designed to operate in puddled soil in lowland rain-fed or irrigated paddy fields, with the operator supplying the necessary energy via a hand-operated crank. The components of the machine include the frame, to which all other elements are attached, the floating board that enables the transplanter to float on top of water or in puddled soil, the seedling tray that serves as a temporary holding area for seedlings before they are finally transplanted, and the transplanting arm responsible for picking and planting the seedlings. Washed seedlings, sourced from the established nursery of two rice varieties, FARO 44 and FARO 52, at two age levels (14 days and 21 days old), are loaded onto the trays, Baptista et al. (2025). The operator pulls the machine backward using the handle, activating the crank mechanism attached to the camshaft. This manual input drives the two cams, which control the planting fork/arm, enabling the forks to pick up seedlings and deposit them into the mud with a downward stroke. The process continues until all planting is complete, with the floating base and transplanting fingers maintaining soil contact.

2.4 Selection of Transplanting Speed

To determine the operator's transplanting speed for the constructed rice transplanter, the theoretical field capacity and operational parameters must be carefully analyzed. The transplanter was designed to achieve a theoretical field capacity of 0.13 ha/day, assuming an 8-hour working day, which translates to a theoretical transplanting capacity of 0.01625 ha/hour. The provided equation for calculating the theoretical field capacity by Hossain & Islam (2025) and Ayoub & McDaniel (1974) was used:

$$\text{Theoretical Capacity, Co} = \frac{W \times S}{10} \qquad (1)$$

Where:
Co = theoretical field capacity in hectares per hour (ha/hr),
W = width of the cut in meters (m),
S = speed in kilometers per hour (km/hr),
10 is a constant to adjust the units appropriately.
Assumption: A width of cut (W) 0.6 m was used for the two-row transplanter, which corresponds to 30 cm spacing between rows, as recommended in literature (Attanda *et al.*, 2023; Chaudhary *et al.*, 2021)

Co = 0.01625 ha/hr (from 0.13 ha/day ÷ 8 hr).
W = 0.6 m (effective width for two rows at 30 cm spacing: (2–1) × 0.3 m).
Using equation (1):
$S = \frac{(0.01625 \times 10)}{0.6}$ = 0.2708 km/h = 0.27 km/h.

2.5 Determination of the Weight Frame of the Machine

The frame serves as the structural framework of the rice transplanter, providing support for the planting mechanism, seedling trays, and other key components. To ensure adequate strength without excessive weight, it was constructed using 25 mm square mild steel pipes with a 3 mm wall thickness. Its lightweight design enhances maneuverability and flotation. The weight and cross-sectional area were calculated using:

$$W = \rho \times g \times V \tag{2}$$

Given that:

- Outer square pipe dimension: L=25 mm=0.025 m
- Wall thickness: 3 mm =Inner side: 22 mm=0.022 m
- Steel density: ρ=7840 kg/m^3
- Gravitational acceleration: g =9.8 m/s
- Total pipe length: Ltotal =4.305 m

The cross-sectional area A of the hollow square pipe was determined as:

$$A = (L \times B) - (l \times b) \tag{3}$$

$$A = (0.025 \times 0.025) - (0.022 \times 0.022) = 0.000625 - 0.000484 = 0.000141m2$$

The total length of pipes used in constructing the chassis, based on the engineering drawing, was 4.305 m. Hence, the volume of steel used was calculated as:

$$Volume\ (V) = A \times L \tag{4}$$

Where:
A is the cross-sectional area of the pipe
L is the total length of the pipe

$$V = 0.000141\,m2 \times 4.305\,m = 0.000607\,m3$$

Using the standard density of mild steel (ρ=7840 kg/m^3) and gravitational acceleration (g=9.8 m/s^2), the weight of the frame was determined using equation 3.2 as:

$$W = 7850\,kg/m3 \times 9.8\,m/s2 \times 0.000607\,m3 = 46.43N$$

Thus, the weight of the frame of the rice transplanter was calculated as 46.43 N

2.6 Determination of the Weight Transplanter Handle

The handle is designed for pulling the implement. It is constructed in a manner that allows for easy pulling of the implements without bending or sideways thrust. The handle was made from a hollow pipe with a diameter of 30mm and is intersected at the end with a 300mm long pipe of the same diameter to improve pulling efficiency.
Given that:
Outer diameter = 30mm, outer radius =15mm=0.015m
Wall thickness 1.5 mm So, inner radius:
R_{inner} = 0.015−0.0015=0.0135 m
Length: L=1.676m
Density of mild steel: ρ=7850 kg/m^3
Gravitational acceleration: g=9.8 m/s^2
The volume of the hollow cylindrical pipe is given as

$$V = \pi\,(R_{outer}^2 - R_{inner}^2) \times L \tag{5}$$

$V = \pi\,(0.015^2 - 0.0135^2) \times 1.676 = 0.000225$ m3
Therefore, the weight of the handle is calculated using equation 3.2 as

$$W = 7850 \times 9.8 \times 0.000225 = 17.15N$$

2.7 Determination of the Weight Floating Base Plate

The floating base plate was constructed from treated hardwood, 25 mm thick, selected for its natural buoyancy and resistance to waterlogging. It was designed to fit securely onto the bottom of the frame, enhancing flotation and ensuring stability in waterlogged paddy fields. The base plate measures approximately 0.525 m × 0.802 m. Details of the floating base configuration and material specifications are presented in the Appendix. A

Given that:

- Length (L) = 0.802 m
- Width (W) = 0.525 m
- Thickness (T) = 25 mm = 0.025 m (typical for flotation panels)
- Wood Density (ρ_p) = 600 kg/m³ (for hardwood)
- Water Density (ρw) = 1000 kg/m³
- Gravitational Acceleration (g) = 9.8 m/s²

The volume of the wooden base plate was determined using the volume equation as;

$$V = L \times W \times T \quad (6)$$

$V = 0.802 \times 0.525 \times 0.025 = 0.051875\, m3$

$The\ weight\ of\ the\ wooden\ plate\ was\ determined\ using\ equation\ 1\ as$

$W = 600 \times 9.8 \times 0.01051875 = 61.44\, N$

Thus, the weight and volume of the floating base were calculated to be 61.44 N and 0.01051875 m³, respectively. However, Buoyancy is applied in the design of a manual rice transplanter to ensure that the machine floats and moves easily over waterlogged or muddy paddy fields. It reduces the effective weight acting on the soft ground, preventing the machine from sinking, minimizing operator effort, and maintaining stable operation. This enhances field maneuverability, preserves transplanting depth and spacing, and protects young seedlings during operation. Applying buoyant force if fully submerged, where the density of water is considered.

$$Fb = \rho w \times g \times V \quad (7)$$

$Fb = 1000 \times 9.8 \times 0.01051875 = 103.08\, N$

Therefore, the net buoyant force for lift capacity was determined as the difference between the buoyant force and the weight of the base.

$$Fnet = Fb - W \quad (8)$$

$Fnet = 103.08 - 61.44 = 41.64\, N$

Buoyancy was strategically factored into the design of the manual rice transplanter to optimize its performance in the challenging conditions of waterlogged or muddy paddy fields. By incorporating a floating base plate constructed from treated hardwood, the transplanter benefits from a buoyant force of 103.08 N when fully submerged, exceeding the base plate's weight of 61.44 N. This results in a net buoyant force of 41.64 N, which effectively reduces the machine's weight acting on the soft ground. This reduction prevents sinking, minimizes the operator's effort, and ensures stable operation, thereby enhancing field maneuverability.

2.8 Determination of the Weight of the Seedling Tray

The paddy seedling tray is constructed from a 1" galvanized plate. It serves to hold rice plant seedlings, which the planting arm uses to pick the plants for sowing into the ground. Two trays, each measuring 530 mm × 450 mm and constructed from 1.5 mm-thick galvanized steel, are positioned at a 60° angle. The slanted orientation utilizes gravity to facilitate the flow of seedlings toward the planting mechanism, ensuring smooth feeding during operation.

Considering galvanized steel (density ρ = 7850 kg/m³), the volume per tray was calculated using the volume equation:

$$Vt = Length \times Width \times Thickness \quad (9)$$

$Vt = 0.53\, m \times 0.45\, m \times 0.0015\, m = 0.000358875\, m3$

The weight of each tray was calculated using equation (1) as:

$Wt = 7850\, kg/m3 \times 9.8\, m/s2 \times 0.000358875\, m3 = 27.5\, N$

For the two trays, the total weight becomes:

$Wtotal\ trays = 27.5 \times 2 = 55.0\, N$

Thus, the weight of the trays was calculated as 50N

2.9 Determination of Draft of the Rice Transplanter

The draft of the transplanter consists of two components: the weight of the transplanter and the frictional losses in the bearings and transplanting mechanism. The following relationship by Hossain., & Islam (2025) was used:

$$D = Dr + F \tag{10}$$

Where;

D = Total Draft

D_r = Rolling Resistance of the wetted soil

F = Frictional Losses

The resistance due to the effective weight was calculated as:

$$Dr = Wt \times R \tag{11}$$

Where:

Wt= Effective weight of the transplanter = 261.71 N (total weight 303.35 N minus buoyant force 41.64 N)

(R) = Coefficient of resistance on wetted soil = 0.03 (assumed consistent with puddled conditions)

$Dr = 261.71N \times 0.03 = 7.85N$

Frictional losses are estimated as 15% of the effective weight, reflecting resistance in the crank, bearings, and arm movement:

$F = 0.15 \times 261.71 = 39.26\ N$

Therefore, the total draft is the sum of resistance and frictional losses:

$$D = Dr + F \tag{12}$$

$D = 7.85\ N + 39.26\ N = 47.11\ N$

2.10 Power Requirement

The machine is manually powered by the operator's pulling force through the crank mechanism. The power requirement is calculated using the following relationship (Rajib *et al.,* 2016).

$$P = D \times S \tag{13}$$

Where:

P = Power in Watts (W)

D = Total draft of the transplanter in Newton (N)

S = backward speed of the transplanter (m/s)

We know that the total draft is 47.11N and the backward speed is 1.5m/s, the power is thus calculated as:

$P = 47.11\ N \times 1.5\ m/s = 70.67W$

The power required is 70.67 W, which is less than the average human power capacity of 76 W. Therefore, the machine was operated without excessive effort

2.11 Cam Shaft Drive Mechanism

The cam shaft, a critical component mounted on the frame, is directly driven by a manual crank operated by the operator. This motion provides the necessary oscillatory mechanism to power the transplanting arms through the cams. The cam shaft, with a diameter of 30 mm, was constructed from mild steel and fitted with cams to control the planting fork/arms.

The camshaft serves two primary functions:

i. To harness the manual rotational input from the crank and convert it into oscillatory motion, which powers the transplanting arms in the planting process.

ii. To hold the cams and their accompanying mechanism, which operate to transmit the necessary motion and speed required for planting seedlings.

The design parameters, including the camshaft length and cam placement, were evaluated based on rice planting requirements (inter-row and intra-row spacing) and the manual operation constraints. Rajamanickam (2021) found that transplanting spacings of 25 cm × 25 cm, 30 cm × 30 cm, and 35 cm × 35 cm performed significantly better than 15 cm × 15 cm and 20 cm × 20 cm. Therefore, based on the transplanting spacing ranges reported by Rajamanickam (2021), the middle range (30 cm × 30 cm) is adopted for this design. Consequently, a distance of 30 cm was selected as the standard spacing for rice.

2.12 Determination of the Angular Speed of the Cam Shaft

The camshaft's angular speed was calculated based on the manual crank input system to achieve the desired planting rate. The following equations are used as adapted from Rajib *et al.* (2016).

$$\omega = \frac{2\pi N}{60} \tag{14}$$

Ncam = Ncrank ×gear ratio

Where:

ω= angular speed of the camshaft in rad/s

Ncam = revolutions of the camshaft per minute (rpm)

Ncrank = revolutions of the crank per minute (rpm)

Gear ratio = ratio of camshaft speed to crank speed

Camshaft speed: $Ncam = 60 \times \frac{14}{23} = 36.52 rpm$

The angular speed of the camshaft is then:

$\omega = \frac{2 \times \pi \times 36.52}{60}$ = 3.82 rad/s

Planting rate verification: With 6 lobes per cam revolution and 2 rows (arms):

$Planting\ rate = Ncam \times lobes \times rows$

$Planting\ rate = 36.52 \times 6 \times 2 = 439\ seedlings/min$

The camshaft's angular speed was determined as approximately 3.82 rad/s at 36.5 rpm, achieved with a 14T:23T sprocket ratio at a 60-rpm crank speed. With 6 lobes per cam revolution and two planting arms, the system delivers about 439 seedlings/minute, which closely matches the target of 450 seedlings/minute, ensuring the transplanting mechanism operates at near-design efficiency.

2.13 Determination of Planting Parameters

The planting distance of 300 mm, adopted from Rajamanickam (2021) as the standard spacing for rice, was used to calculate the effective planting rate. In this design, planting is governed by the camshaft's revolutions, driven by the crank–sprocket system, rather than a ground wheel.

Each revolution of the camshaft activates six lobes, and each lobe results in a planting action. Since two arms are working alternately, the total number of seedlings transplanted per camshaft revolution is:

$$Np = l \times nf \tag{16}$$

Where:

Np = number of seedlings per camshaft revolution

l = number of lobes per revolution = 6

nf = number of arms = 2

$Np = 6 \times 2 = 12\ plants\ per\ camshaft\ revolution$

The camshaft speed is obtained from the sprocket ratio (14T:23T):

$$Ncam = Ncrank \times \frac{14}{23} = 60 \times \frac{14}{23} = 36.5\ rpm$$

Thus, the total number of seedlings planted per minute is:

$s = Np \times Ncam = 12 \times 36.5 = 438\ plants/mins$

2.14 Shaft Design

Determination of the Cam Shaft Diameter

The camshaft drives the planting mechanism via the sprocket and chain system, receiving torque from the crank through the 14-tooth driver sprocket (crank) and 23-tooth driven sprocket (camshaft). The shaft is subjected to torsional stresses from power transmission and bending stresses from the transplanting arms. Therefore, the shaft was designed as a solid circular shaft using standard mechanical design procedures based on the maximum shear stress theory (Kavitkar *et al.*, 2017), incorporating appropriate safety factors.

$$d^3 = {}^{16}/_{\pi Sa} X \sqrt{(K_b x M_b)^2 + (K_t x M_t)^2} \tag{17}$$

d = diameter of the shaft

K_b= Combine shock fatigue factor for bending

K_t= Combine shock fatigue factor for torsion

M_b= maximum bending moment

M_t= Torsional moment

S_a= maximum allowable shear stress

Assumptions and Material Properties:

Material: Mild steel.

Maximum allowable shear stress (30 MPa.)

Combined shock fatigue factors: Kb = 1.5 (bending), Kt = 1.5(torsion).

Operator pulling speed: 1.5 m/s walking speed, crank input at 60 rpm.

Camshaft speed (N_2): 36.5rpm

Estimation of Bending Moment (Mb)

The camshaft supports the weight of two cams and the transplanting arms. Assuming a total weight of 103 N (from the transplanting arm calculation) distributed over a 0.3 m shaft length, and modeled as a supported beam with a central load. Using Equation 18, the shaft bending moment becomes

Where:

F = 103 N (total weight of arms),

L = 0.3m

$$Mb = \frac{F \times L}{4} \tag{18}$$

$$Mb = \frac{103 \times 0.3}{4} = 7.725\text{Nm}$$

Estimation of Torsional Moment (Mt)

The torsional moment is derived from the power transmitted through the sprocket system. The total power requirement, based on the draft (47.11 N) and backward speed (1.5 m/s), is 70.67 W. This power is input at the crank (60 rpm), and the torque is reduced at the camshaft due to the gear ratio.

Crank angular speed:

$$\omega\text{crank} = \frac{2 \times \pi \times 60}{60} = 6.28 \text{ rad/s}$$

Crank torque (based on 70.67 W at 36.5 rpm):

$$\text{Tcrank} = \frac{P}{\omega\text{crank}} = \frac{70.67}{6.28} = 11.25 \text{ Nm}$$

Since torque increases when speed is reduced (by the sprocket ratio):

$$Tcam = Tcrank \times \frac{Ncrank}{Ncam} = 11.25 \times \frac{60}{36.5} = 18.5\, Nm$$

Thus, the camshaft torque is approximately 18.5 Nm.

Determination of Shaft Diameter: Using the maximum shear stress theory for combined loading (Kavitkar et al., 2017):

$$d^3 = {}^{16}\!/_{\pi Sa} X \sqrt{(K_b x M_b)^2 + (K_t x M_t)^2}$$

Substituting known values:

$$d^3 = {}^{16}\!/_{\pi} \times 30 \times 10^6 X \sqrt{(1.5 \times 7.725)^2 + (1.5 \times 18.5)^2} = 17 \text{ mm}$$

Final Shaft Size with Factor of Safety

To ensure structural safety and account for stress concentrations and unaccounted loads, a 20% factor of safety was applied: final = 17 mm + 20% = 17 + 3.4 = 20.4 mm.

A mild steel shaft with a diameter of 20 mm (standard commercial size) was selected to ensure sufficient strength and account for stress concentrations.

Planting Unit

When designing the planting mechanism, several aspects were considered, including:

i. Plant Catching Mechanism
ii. Depth of Planting

RESULTS AND DISCUSSION

Force and Stress Analysis of the Transplanting Fingers

The transplanting fingers endure a total working force of approximately 35.0 N, comprising a soil penetration component (29.7 N)—based on established literature—and an amplified tangential seedling-extraction component (5.3 N), derived by applying a 1.5 × dynamic amplification factor to the experimentally determined tangential force range (3. 68–4.70 N) (Kavitkar et al. (2017). This combined

loading scenario was used to analyze bending stress, deflection, and fatigue resistance, ensuring the structural reliability of the transplanting fingers under actual field conditions.
The dynamic force becomes:

$$Fdynamc = Fstatic \times DAF \quad (19)$$

$$Fdynamc = 35.02 \times 1.5 = 52.53\,N$$

The total force per arm (from two fingers):

$$Ftotal\,per\,arm = 52.53 \times 2 = 105.06\,N$$

The resulting bending moment on the arm (assuming the load acts at the distal end, 0.52 m away):

$$M = Fdynamic \times L \quad (20)$$

$$M = 105.06 \times 0.52 = 54.63\,Nm$$

The section modulus for the arm (100 mm × 10 mm rectangular cross-section):

$$Z = \frac{bh^2}{6} \quad (21)$$

$$Z = \frac{0.1 \times 0.01^2}{6} = 1.67\times10^{-7}\,\text{m}^3$$

$$\sigma = \frac{M}{Z} = \frac{54.63}{1.67\times10-7} = 327\,\text{MPa}$$

With an allowable stress of:

$$\sigma allowable = \frac{Sy}{FOS} = \frac{600}{1.5} = 400\,\text{MPa}$$

Deflection Analysis:
The maximum deflection under load:

$$\delta = \frac{FL^3}{48EI} \quad (22)$$

where:
E = 200GPa

$$I = \frac{bh^3}{12} = \frac{0.1\times(0.01)^3}{12} = 8.33\times10^{-9}$$

$$\delta = \frac{105.06\times(0.52)^3}{48\times200\times109\times 8.33\times10-9} = 0.00089\text{m (0.89 mm)}$$

This is < 1 mm, in line with literature recommendations for rigid planting arms.

Fatigue Analysis
With cyclic bending, the endurance stress is taken as half the maximum:

$$\sigma endurance = \frac{327}{2} = 163.5\,MPa$$

This lies within the 150–200 MPa endurance band for mild steel, ensuring fatigue resistance. With a factor of safety of 2 applied, the design is acceptable for continuous oscillations during planting.

Oscillation and Planting Rate Performance
The rate of oscillation of the planting fingers or mechanism is equivalent to the rotational speed of the driven sprocket powering it.

$$Np = Ncam \quad (23)$$

Where:

- Np = rate of oscillation of planting fingers (rpm)
- Ncam = speed of the camshaft (rpm)

From the sprocket ratio (14T driver: 23T driven):

$$Ncam = Ncrank \times \frac{14}{23} = 60 \times \frac{14}{23} = 36.5\,rpm$$

Thus, the rate of oscillation of the planting fingers was calculated as 36.5 rpm

Number of Seedlings Transplanted per Minute
Each revolution of the camshaft produces six oscillations (lobes) per planting arm. With two arms operating alternately, the total seedlings transplanted per minute is given by:

$$s = nf \times l \times Np \quad (24)$$

Where:

Nadungu *et al.*, (2024). Development and Performance Evaluation of a Manually Operated Two-Row Rice Transplanter. *Nigeria Journal of Engineering Science Research (NIJESR)*, 7(1): 103-115. https://doi.org/10.5281/zenodo.17286609

s = number of seedlings transplanted per minute
nf = number of arms (2)
l = number of lobes per camshaft revolution (6)
Np = camshaft speed (36.5 rpm)
$s = 2 \times 6 \times 36.5 = 438 plants/min$

Handle Assembly

The pulling handle was fabricated from a 1-inch diameter steel pipe, bent to form a comfortable U-shaped grip, and fixed at a length of 1,012 mm. The handle was welded to the frame and reinforced with gussets to prevent bending under manual load. Its ergonomic design ensures forward propulsion without lateral torque or operator fatigue. Details of the specification is provided in Table 1:

Table-1 Specification of the Fabricated Two-Row Manual Rice Transplanter

Parameter	Value
Length of the model	1,922 mm
Width of the model	525 mm
Height of the model	997 mm
Circumference of planting operation	Approx. 900 mm
Power source	Manual (hand-cranked)
Type of wheel	Wooden float (skid type)
Row spacing	300 mm
Depth of planting	30–50 mm
Gear speed ratio	1:1 (via auxiliary shaft)
Handle length	1,012 mm

The data was analyzed using Analysis of Variance (ANOVA) to evaluate the main effects of speed, variety, and age, as well as their interactions. Duncan's Multiple Range Test (DMRT) was applied to determine significant differences among treatment means, addressing key research questions such as optimal operating speed, seedling suitability, and planting uniformity. The ANOVA framework for this 3×2×2 factorial experiment in RCBD

Performance Indicators

The performance of the two-row manual crank rice transplanter was quantified using the following machine parameters, with formulas derived from established literature (Mehta et al. (2014); Mohapatra et al. (2023):

i. Transplanting Efficiency (TE)

Transplanting efficiency measures the percentage of seedlings successfully transplanted into the soil with proper placement and orientation. It was calculated using the equation by (Manikyam *et al.*, 2020):

$$TE = \left(\frac{Nst}{Nsp}\right) \times 100 \quad (25)$$

Where:
Nst = Number of successfully transplanted seedlings
Nsp = Total number of seedlings picked by the transplanter

ii. Effective Field Capacity (EFC)

Effective field capacity represents the actual area covered per unit time, reflecting the transplanter's operational efficiency. It was determined using the equation cited by Mohapatra et al. (2023):

$$EFC = \frac{Aa}{Tt} \quad (26)$$

Where:
Aa = actual area covered, m2
Tt = total time taken, h

iii. Percentage Floating Hills

The percentage of floating hills refers to the proportion of transplanted hills that failed to establish firm anchorage in the soil and remain suspended or displaced due to poor contact with the puddled field. These floating hills typically result in poor crop establishment and lower yields. It was calculated using the formula adapted from Mehta et al. (2014):

$$PFH = \frac{FH}{TYH} \quad (27)$$

Where:
PFH= Percent floating hills, %
FH = number of floating hills in a sample area
TFH= Total number of hills in sample area

iv. Percentage Missing Hills

This parameter quantifies the planting gaps or positions where the transplanter failed to deposit seedlings. It serves as an indicator of planting accuracy and uniformity. The percentage of missing hills was computed using the equation from Mohapatra *et al.* (2023):

$$PMH = \frac{Hm}{\mathrm{Hi}} \tag{28}$$

Where
Hpm = missing hills, %
Hm = total number of missing hills in sample area
Hi = total number of hills

v. Establishment rate %

Establishment rate is defined as the percentage of successfully established hills—i.e., hills where seedlings not only were deposited but also remained viable and rooted after a given period (e.g., 5–7 days post-transplanting). It provides a realistic measure of transplanting success and seedling survival. It is expressed as:

$$Establishment\ rate\ (Er) = \frac{He}{Hi} \tag{29}$$

Where:
He=$number\ of\ established\ hills$
Hi = total number of hills

CONCLUSION

A two-row rice transplanter was designed, constructed and evaluated. The performance evaluation focused on key response variables, including row spacing, number of plants per hill, missing hills, field efficiency, sinkage, and puddling index. The effects of independent variables operational speed (0.3, 0.45, and 0.6 m/s), rice variety (FARO 44 and FARO 52), and seedling age (14 and 21 days) were analyzed using Analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT. The machine provides a viable, low-cost option for smallholder rice farmers looking to enhance productivity and reduce labor costs.

CONFLICT OF INTEREST

The authors declare no competing interest

ACKNOWLEDGEMENT

This study did not receive any specific grant from funding agencies in public, commercial or not-for-profit sectors.

REFERENCES

Akpokodje, G., Lançon, S. O., & Erenstein, O. (2001). Nigeria's rice economy: State of the art. Paper presented at the NISER/WARDA Nigerian Rice Economy Stakeholders Workshop, Ibadan, 8-9 November 2001. Bouake: WARDA.

Attanda, M. L., Muhammad, A. I., & Nuhu, I. S. (2023). Development of a two-row manually operated rice transplanter for smallholder farmers in Nigeria. *Algerian Journal of Engineering and Technology*, 8, 63–73. https://doi.org/10.57056/ajet.v8i1.92

Ayoub, M. M., & McDaniel, J. W. (1974). Effect of operator stance on pushing and pulling tasks. *AIIE Transactions*, 6, 185–195.

Baptista, R. G., Bielza, M. R., Olivas, C. A., Razote, R. P., Agcaoili, S. O., Galvan, J.P.D., Adorio, M.D., Ruth, M., &Simon, A.C. (2025). Design and development of a mechanical rice transplanter. *Journal of Agricultural Engineering*, 26(5), 66–73.

Chaudhary, A., et al. (2021). Optimization of rice transplanter performance using CCD. *Journal of Agricultural Engineering*, 58(1), 122–130. https:// doi.org/10.52151/jae2021581.1755

Durga, M. L., Rao, A. S., & Kumar, A. A. (2020). Performance evaluation of single row-low horse power tractor operated vegetable transplanter. *Current Journal of Applied Science and Technology*, 37, 37–44. https://doi.org/10.9734/cjast/2020/v39i4431149

Hossain, F., & Islam, S. (2025). Impact of transplant age on the yield and yield contributing characteristics of cherry tomato varieties (*Solanum lycopersicum* var. *cerasiforme*). *Journal of Agroforestry and Environment*, 18(1), 44– 51.

Kavitkar, C. R., Aware, V. V., Patil, M. R., Shahare, P. U., Dhande, K. G., Shirsat, N. A., & Aware, S. V. (2017). Optimization of paddy nursery age for manual paddy transplanter (hand cranking type). *International Journal of Agricultural Engineering*, 10(1), 141–145. https://doi.org/10.15740/ has/ijae/10.1/141-145

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. http://www.phytojournal.com

Mehta, C. R., Chandel, N. S., & Senthilkumar, T. (2014). Status, challenges and strategies of farm mechanization in India. *Agricultural Mechanization in Asia, Africa and Latin America*, 45(4), 43–50.

Mohapatra, K. K., Nayak, A. K., Patra, R. K., Tripathi, R., Swain, C. K., Moharana, K. C., Kumar, A., Shahid, M., Mohanty, S., Garnaik, S., Nayak, H. S., Mohapatra, S., Nagothu, U. S., & Tesfai, M. (2023). Multi-criteria assessment to screen climate smart rice establishment techniques in coastal rice production system of India. *Frontiers in Plant Science*, 14, 1130545. https://doi.org/10.3389/fpls.2023.1130545

Pasuquin, E., Lafarge, T., & Tubana, B. (2008). Transplanting young seedlings in irrigated rice fields: Early and high tiller production enhanced grain yield. *Field Crops Research*, 105(1), 141–155. https://doi.org/10. 1016/j.fcr.2007.09.001

Pimpalgaonkar, S. M., Sapate, T. P., Baghel, S. K., Wadibhasme, V. D., Thosar, S. S., & Bawane, S. W. (2020). Design and development of rice transplanting machine. *International Research Journal of Engineering and Technology (IRJET)*, 7(3), e-ISSN: 2395-0056. www.irjet.net

Rajamanickam, G., (2021). Fabrication of semi-automatic paddy transplanter. *IOP Conference Series: Materials Science and Engineering*, 1059, 012064. https://doi.org/10.1088/1757-899x/1059/1/012064.

Rajib, B. (2016). Design and fabrication of paddy transplanter. *Engineering Science and Technology: An International Journal (ESTIJ)*, 6(4), ISSN: 22503498.

Rajvir, Y., Patel, M., Shukla, S. P., & Pund, S. (2007). Ergonomic evaluation of manually operated six row paddy transplanter. *International Agricultural Engineering Journal*, 16(3–4), 147–157.

Rickman, J. F., Mussgnug, F., Khanda, C. M., Satpathy, S. D., Parida, N., Singla, K., Kumar, V., Banik, N. C., Iftikar, W., Mishra, A., Yadav, S., Malik, R. K., & McDonald, A. J. (2015). Operational manual for mechanical transplanting of rice. *Cereal Systems Initiative for South Asia (CSISA)*. https://csisa.org/wp-content/uploads/sites/2/2014/06/ Operational-Manual-for-Mechanical-Transplanting-of-Rice. pdf

Singh, K., Singh, S. R., Singh, J. K., Rathore, R. S., Singh, S. P., & Roy, R. (2013). Effect of age of seedling and spacing on yield, economics, soil health and digestibility of rice (*Oryza sativa*) genotypes under system of rice intensification. *Indian Journal of Agricultural Sciences*, 83(5), 479–483.

Singh, J. (2018). Development of a transplanting mechanism model for power operated rice transplanter using graphical method. *International Journal of Current Microbiology and Applied Sciences*, 7(12), 298–305. https://doi.org/10.20546/ijcmas.2018.712.036

Sultan, T., Rashed, R. U., Shawan, S. I., Swapan, K. P., & Sarkar, A. R. (2018). Effect of age of seedlings at staggered planting and spacing on growth and yield of transplant Aman rice (Cv. BRRI Dhan 46). *Advances in Biotechnology and Microbiology*, 11(2), 43–47. https://doi.org/10.19080/AIBM. 2018.11.555808

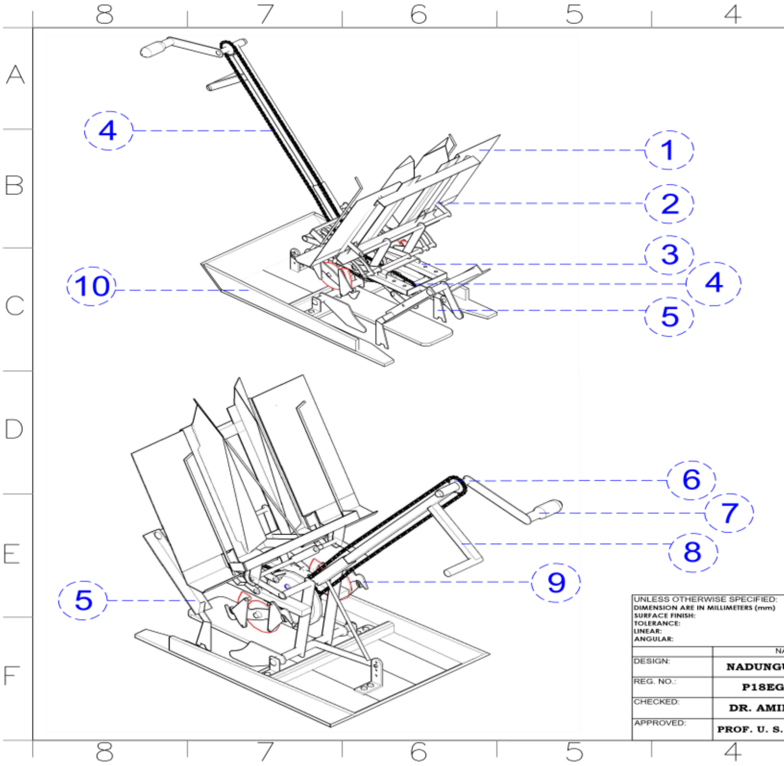
Tupkar, A. B., Bitturwar, A. S., Shende, M., Pande, P. R., & Tonge, V. J. (2020). An approach on rice planting machine. *International Advanced Research Journal in Science, Engineering and Technology*, 7(1), ISSN: 2393-8021. https://iarjset.com/wp-content/uploads/2020/ 02/IARJSET.2020.7118

Vasudevan, S. N., Basangouda, Mathad, R. C., Doddagoudar, S. R., & Shakuntala, N. M. (2014). Standardization of seedling characteristics for paddy transplanter. *Journal of Advanced Agricultural Technologies*, 1(2), 141–146.

Yanmar. (2016). Rice transplanter VP7D25 operation manual. https://www.yanmar.com/media/en_vn/2016/operationmanual/ manual_VP7D25_en.pdf

APPENDIX. A

MATERIAL SPECIFICATIONS



S/N	PART DESCRIPTION	MATERIAL	QTY	REMARK
10	Machine Stand	Wood	1	Constructed
9	Feeding Mechanism	Mild Steel	2	Constructed
8	Frame Support Handle	Mild Steel	1	Constructed
7	Pedal Handle	-	1	Constructed
6	Sprocket	Mild Steel	4	Standard
5	Planting Mechanism	Mild Steel	2	Constructed
4	Chain	Mild Steel	2	Standard
3	Main Frame	Mild Steel	1	Constructed
2	Tray Frame	Mild Steel	1	Constructed
1	Seedling Tray Holder	Alluminium	2	Constructed

UNLESS OTHERWISE SPECIFIED: DIMENSION ARE IN MILLIMETERS (mm) SURFACE FINISH: TOLERANCE: LINEAR: ANGULAR:		INSTITUTION: AHMADU BELLO UNIVERSITY, ZARIA		DEPARTMENT: DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCES ENGINEERING, I.A.R / A.B.U. ZARIA
	NAME	SIGNATURES	DATE	TITLE: RICE TRANSPLANTING MACHINE
DESIGN:	NADUNGU GAGARE			
REG. NO.:	P18EGAE8044			
CHECKED:	DR. AMINU SALEH		MATERIAL:	ISOMETRIC VIEW — A3
APPROVED:	PROF. U. S. MOHAMMED		DRW. NO.: 1	SCALE: 1 : 20