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Original Article

# Development of a two-row manually operated rice transplanter for smallholder farmers in Nigeria

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**ABSTRACT**

A two-row rice transplanting machine was developed for smallholder farmers in Nigeria using standard-approved methods and locally available materials. The transplanter was designed in such a way that one operator can operate the machine. The machine consists of ground wheels, sprockets, chain, frame, float, transplanting mechanism, seedling tray, shaft and handle. The developed rice transplanter was evaluated based on a 2 x 2 x 3 factorial experimental design arranged in a strip plot design to ascertain its operational performance. The performance parameters of the rice transplanter revealed a field capacity and efficiency of 0.0146 ha/h and 55.66%, respectively. A variation in the distance between the hills was observed. The mean values were found to be 322.9 mm. The number of seedlings dispensed per hill varied in different plots. In most cases, 2-3 numbers of seedlings are dispensed per hill. The depth of the hill varies between 23 mm to 38 mm respectively. The mean depth was found to be 30.33 mm. The mean percentage of the missing and floating hills was 40% and 45%, respectively. The missing and floating hills were high in the transplanted plot. Results obtained from the analysis of variance show that the effects of treatment tillage operation and water depth have a significant effect on the machine. Based on the result obtained it can be concluded that more performance evaluation with machine and soil parameters needs to be conducted on the machine. This technology is recommended for use in rural areas to increase productivity by rice farmers.

## 1. Introduction

Rice *(Oryza sativa)* is considered as a staple food in most Africa countries, Asia, and other parts of the world. This is the most important staple food for about half of the human race [1]. Saka and Lawal [2] classified rice as the most important food depended upon by over 50% of the World population for about 80% of their food need. Food and Agricultural Organization [3] estimated that annual rice production should be increased from 586 million metric tons in 2001 to meet the projected global demand of about 756 million metric tons by 2030. The annual national demand of rice in Nigeria was estimated at 7.8 million metric tons and its annual production exceeded at 12.85 million tons in 2018 [4].

Transplanting is one of the major processes for the establishment of a paddy field, and involves seedlings preparation in nurseries where they grow for about 15 to 40 days. After which, the seedlings are uprooted and transplanted onto a larger rice field either manually or using machines [5]. Manual hand transplanting does not require costly machines and is most suited for labour-surplus areas and small rice fields. Manual transplanting is done in fields with less than optimal levelling and with varying water levels.

Mechanical transplanting of rice is the process of transplanting young rice seedlings using specialized equipment known as a rice transplanter. A common rice

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transplanter comprised of mechanical linkages to plant the seedling, a tray to hold the seedlings, a frame, fork, handle and the ground wheel. It can plant two, three or up to six rows of seedlings at a time and a constant distance. Extensive efforts have been made to achieve high rice yield through whole process mechanization, which in turn contributes to saving labour and improving production efficiency [6,7]. Mechanical Direct Seeding (MDS) and Mechanical Transplanting of Rice (MTR) are two main mechanized planting methods of rice. Mechanical Transplanting of Rice (MTR) is a cost-effective establishment method for rice when compared to the existing and common method of hand transplanting. The primary drivers of the adoption of machine transplanting are rising labour scarcity and the high costs associated with hand transplanting. Mechanical transplanting when compared with the manual transplanting method could save up to 45% and 60% of transplanting and labour costs, respectively [5]. In addition, mechanical transplanting guarantees good crop stand and increased yield compared to hand manual transplanting [8].

According to Hossen et al [5], the first hand-push rice transplanter was invented in Japan, with about 50 thousand units introduced to the market during 1960-1965. The rice transplanter was a single-row machine weighing from 25 to 28 kg. The machine comprised a seedling platform, handles, ground drive wheel, and a float, and uses rice seedlings band of 12 to 15 cm height. The transplanting machine can cover a 1-ha field in 25 - 30 h. Then came a four-row manual rice transplanter in 1964 at the National Institute of Agricultural Engineering in the United Kingdom. This machine was tested in 1996 at Tractor Training and Testing Station, Budni. A single operator can handle this machine to coverer up to 0.05 ha/h under optimum conditions. Jayasundara et al. [9] developed and introduced a motorized modification of the rice transplanter capable of planting seedlings at 20×20 cm intervals. The machine is simple to construct and easy to operate and is easy for operators irrespective of female or male to successfully transplant seedlings.

However, a review of the literature on rice transplanting operations revealed little or no information on the development and operation of transplanting equipment and machinery in Nigeria. Transplanting machines that are successful in countries such as Japan, China, India and Korea are too costly and not adaptable to the farming and cropping system of smallholder farmers in Nigeria with capacity beyond what medium farmers require. However, numerous studies reported several constraints and challenges in the manual hand transplanting of rice seedlings amongst smallholder farmers in Nigeria. Based on a preliminary survey conducted among smallholder farmers' rice clusters in Northern Nigeria in 2018, there are no machines for rice transplanting at the disposal of the smallholder farmers.

Manual hand transplanting of rice seedlings is the predominant practice of rice transplanting in these areas. Islam et al. opined that the labour requirement in manual hand transplanting ranged from 123 – 150 man-h per hectare whereas the mechanical transplanting method is between 9.0 – 10.5 man-h per hectare. This translate to about 19 – 22% (manual hand transplanting) and 1.65 – 2.00% (mechanical transplanting) of total labour requirement in rice production [10]. This method of manual transplanting is very tedious, consumes a lot of energy, and time and is full of fatigue. It is on this background the study focus on the development of a two-row manually operated rice transplanter for smallholder farmers in Nigeria

## 2. Materials and methods

### 2.1.1 Ground wheel

The ground wheel is made of a 3 mm thick mild steel plate cut out into 50 mm width and folded into a circle of 300 mm diameter. The wheel has 3 mm thickness and 20 mm wide flat bars as spokes that are welded to a hub enclosing the bushings.

### 2.1.2 Frame

The frame was made from mild steel 40×40 ×5 mm angle iron with a handle that was constructed from a 25-mm square pipe. The float was fabricated from a mild steel sheet of 1.5 mm thickness.

### 2.1.3 Tray

This is where the seedlings are placed and fabricated from a 2-mm metal sheet.

### 2.1.4 Planting finger

The finger is made from a 4 mm flat bar cut using the gas cutting technique. It is responsible for picking the seedlings from the tray and placing them into the soil.

### 2.1.5 Shaft

A round solid shaft of medium carbon steel of standard size 20 mm diameter of ASME code 50C4 was used. The ASME [11] gave the yield stress as 700 N/mm$^2$ and 460 N/mm$^2$ respectively. The yield stress was reduced, using some failure criteria to obtain the allowable shearing stress of 75.6 N/mm$^2$ that was used for the determination of shaft size.

### 2.2 Materials for the evaluation of the machine

The materials used for the field evaluation included rice seedlings (faro 44) 21 days of planting, a stopwatch, steel tape, a weighing scale (G & G JJ3000Y) and a heart rate monitor (Polar M71ti, Polar Electro Oy, Kempele, Finland).

### 2.3 Component description of the transplanter

The transplanter is a two-row and manually operated machine. The components of the machine include ground wheels, sprockets, chain, frame, float, transplanting mechanism, seedling tray, shaft and handle.

### 2.4 Design consideration of the transplanter

The design of the manually operated two-row rice transplanter planter is based on some design considerations discussed in the subsequent sections.

#### 2.4.1 Plant picking mechanism

There are several parameters which were considered in designing the seedling picking mechanism, they include; place of picking, number of seedlings per picking, a distance of travel, releasing point and angle of planting. The seedlings should not be damaged while picked and released by the planting arm.

#### 2.4.2 Depth of planting

Planting depth is important for the growth of roots and to stand with the submerged condition. The planting depth for the machine is set to be 30 mm below the ground level.

#### 2.4.3 Design of tray

The tray is to carry the seedlings and direct the plants to the planting arm. Basic factors (width, length, and angle) are considered in designing the tray mechanism. A higher angle reduces the energy required to feed the seedlings to the transplanting arm while too much angle effect on falling and compaction of the nursery at the end of the tray making it difficult to take out the plants from the nursery by the transplanting arm. The final angle of the tray is 120°.

#### 2.4.4 Transplanter handle

The length of the handle was calculated based on the average standing elbow height of the female operator. The average standing elbow height of women workers of the Nigerian rice cluster is 85 cm [12] .

### 2.5 Design calculations

#### 2.5.1 Design of transplanter handle

The distance of the wheel centre from the operator in operating conditions is 115 cm and the average standing elbow height of women workers in Kano is 85 cm So, the angle of inclination $\theta_h$ with the horizontal given in equation 1 [13].

$$Tan\ \theta_h = \frac{a_1}{a_2} \qquad (1)$$

Where, $a_1$= height of the centre of the wheel to the elbow = 85 cm Lawan [12] and $a_2$= horizontal distance measured between the normal to the centre of the wheel and normal to the elbow = 115 cm.

$$Tan\ \theta_h = \frac{85}{115}$$

$\theta_h$= Tan$^{-1}$ = 0.7391 = 36$^{o}$

#### 2.5.2 Speed of driving sprocket ($N_1$)

Driving sprocket speed is determined using equation 2 expressed by Chaudhary et al. [14]

$$\omega = \frac{v_{avg}}{r_w} \qquad [2]$$

Where,$v_{avg}$= average walking speed of man (km/h), $r_w$ = radius of wheel (mm), and

$$N_1 = \frac{(\omega \times 60)}{2 \times \pi} \qquad [3]$$

#### 2.5.3 Speed of driven sprocket ($N_2$)

The speed of the driven sprocket is determined in equation 4 as reported by Khurmi and Gupta [15].

$$N_2 = \frac{N_1 \times Z_1}{Z_2} \qquad [4]$$

Where, $N_1$ = speed of driving sprocket (rpm), $N_2$ = speed of driven sprocket (rpm), $Z_1$ = number of teeth on the driving sprocket, and $Z_2$ = number of teeth on the driven sprocket.

### 2.5.4 Sprocket velocity ratio (VR)

The velocity ratio is computed an according to equation 5 by Khurmi and Gupta [15].

$$VR = \frac{Z_1}{Z_2} \tag{5}$$

Where, $Z_1$ = number of teeth on the driving sprocket and $Z_2$ = number of teeth on the driven sprocket.

### 2.5.5 Wheel circumference ($C_w$)

Chaudhary et al. (2005) reported equation 6 as the linear distance travelled by a transplanter in one complete rotation of the wheel or the circumference of the wheel.

$$C_w = D_w \times \pi \tag{6}$$

Where, $D_w$= diameter of the wheel (mm)

### 2.5.6 Distance between two successive hills ($D_s$)

The distance between two successive hills is calculated using equation 7 by Anindita et al. [16].

$$D_s = \frac{C_w}{VR} \tag{7}$$

Where, $C_w$ = wheel circumference (mm) and VR = velocity ratio.

### 2.5.7 Chain length ($L_c$)

The chain length was estimated using equation (8) by Khurmi and Gupta [15].

$$m = \frac{2C}{P} + \left(\frac{Z_1+Z_2}{2}\right) + \frac{(Z_2-Z_1)^2}{2\pi P} \tag{8}$$

Where, p = chain pitch (mm), $Z_1$ and $Z_2$ = number of teeth in the driver sprocket (42) and driven sprocket respectively, m = number of chain links = 88, C = centre to centre distance between two sprockets = 30 to 50$P$.

For this design $C = 30P$ was used.

$C = 30 \times 9.525 = 285.75$ mm

$$m = \frac{2C}{P} + \left(\frac{Z_1+Z_2}{2}\right) + \frac{(Z_2-Z_1)^2}{2\pi P} = 88.06$$

:· Chain length ($L_C$) Khurmi and Gupta [15] as:

$$L_C = m \times p \tag{9}$$

$L_C = 88.06 \times 9.525 = 838$ mm

Where m = number of chain links and $P$ = chain pitch (mm)

### 2.5.8 Velocity of chain (V)

The velocity of the chain is computed according to equation 10 as reported in Khurmi and Gupta [15].

$$V = \frac{Z_1 \times P \times N_1}{60 \times 10^3} \tag{10}$$

Where, $Z_1 = 42$, $P$ = chain pitch (mm), and $N_1$ = speed of driving sprocket (rpm).

### 2.5.9 Shaft diameter

The shaft material used is steel 50C4 with ultimate tensile stress ($\sigma_{ut}$ = 700 N/mm$^2$ and $\sigma_{yt}$ = 460 N/mm$^2$), $K_b$ = 1.5, $K_t$ = 1.5 given by ASME [11]. The permissible shear stress assumed is the total mass M (seedling 5 kg + frame and accessories 20 kg) = 25 kg.

$$\text{Total force, } F = M \times g \tag{11}$$

Where, g = acceleration due to gravity m/s$^2$

Now, considering the Free Body Diagram of the wheel in Fig. 1, the resultant force, $F_1$ is given by

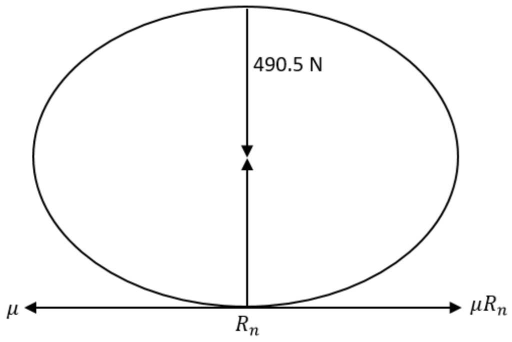

Fig 1. Free Body Diagram

$$F_1 = \mu \times R_n \tag{12}$$

Where, $\mu$ = Frictional Coefficient = 0.33 (metallic wheel) and $R_n$ = Normal Reaction (N)

The torque transmitted (T) is:

$$T = F_r \times r_w \tag{13}$$

$$r_w = \frac{T}{J} = \frac{\tau}{r} \tag{14}$$

Where, $r_w$ = wheel radius (mm), $T$ = twisting moment (or torque) acting on shaft (N-mm), J = polar moment of inertia (mm$^4$) = $\frac{\pi d_s^4}{32}$, τ = torsional shear stress (N/mm$^2$), r = distance from neutral axis to outermost fibre (mm).

$$\frac{75.6}{d_s/2} = \frac{48.45 \times 10^3}{\pi {d_s}^4/32}$$

$$\pi {d_s}^4 = 3263.93$$

$$d_s = 14.833 \text{ mm} \approx 15 \text{ mm}$$

For safety, we selected the shaft diameter $d_s$ = 20 mm for the driving shaft. The same shaft diameter of 20 mm was used for the driven shaft as well as the planting shaft. The length of the shaft is 45 mm.

### *2.5.10 Selection of shaft bearing*

The minimum shaft diameters were used as a guide and a standard bearing with a number of 204 having 47 and 14 mm as outside diameter and width, respectively was selected [15].

### *2.5.11 Fabrication of the machine*

The transplanter was constructed based on the availability of local materials and the cost of the materials. The fabrication of the parts was conducted using simple techniques. The fabrication process comprised the construction of the basic components based on the designed parameters. The design drawing and assembly of the developed transplanter are presented in Fig. 2 and 3, respectively.

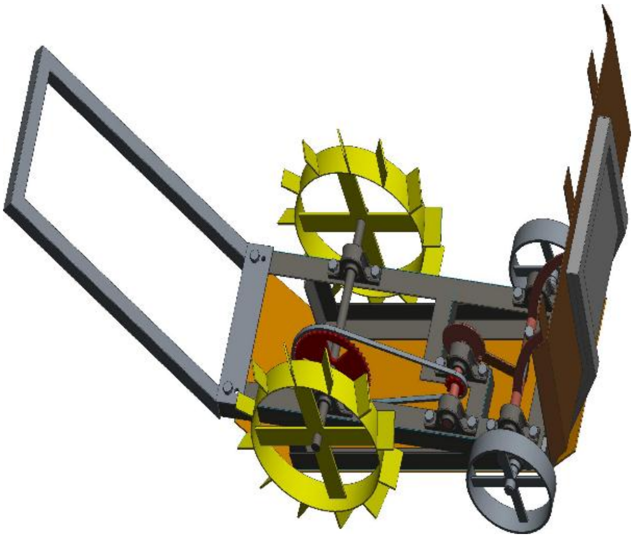

Fig 2. Isometric Drawing of the Transplanter

Fig 3. Assembly of the Transplanter Components

### *2.5.12 Principle of operation of the prototype machine*

The developed prototype machine was designed to transplant two seedlings at a time. In operation, the two ground wheels rotate when the operator pulls the machine from one point to another in the field, which produces torque. The developed torque would then be transmitted to the chain and sprocket assembly, which powers the slider crank mechanism connected with the transplanting finger.

The finger that is operated by the mechanism oscillates and picks up a seedling from the tray and placed it into the soil at a set depth. Fingers are returned to their original position so that, the process can be repeated when the machine moves to the next point of planting.

### *2.6 Performance evaluation of the developed machine*

The prototype transplanter was taken to the farmer to conduct field trials. Fig. 4a and 4b demonstrated the loading of seedlings and the transplanting operation of the rice seedlings, respectively.

Fig 4. (a) Seeding loading and (b) Transplanting of rice seedlings

#### *2.6.1 Experimental site*

The experiment was conducted at Hadejia Jama’are River Basin Authority (HJRBA) field Kadawa, during the 2019 rainy season. The study area is located in the Garun Malam Local Government area in the southern part of Kano State, Nigeria. The area is bordered by Kura and Madobi Local Governments to the north, Rano Local Government to the south, Bebeji Local Government to the west, and Bunkure Local Government to the east. Kadawa is enclosed between latitude $11^0$ 30” N and longitude $8^0$ 30” E.

### *2.7 Field evaluation*

#### *2.7.1 Transplanting speed*

The speed was obtained by recording the time required for the transplanter to travel a 20 m distance in the field. The speed of transplanting was computed using equation 15 [17].

$$S_t = \frac{D}{t} \times 3.6 \qquad (15)$$

Where, $S_t$ = Transplanting speed in (km/h), D = Distance (m), and t = Time required to cover the distance (s).

#### *2.7.2 Theoretical field capacity*

The theoretical field capacity was calculated per equation 16 [17].

$$\text{Theoretical field capacity} = \frac{W\,S}{10} \qquad (16)$$

Where, W = width of operation (m) and $S_t$ = transplanting speed (km/h).

#### *2.7.3 Effective field capacity*

This is the ratio of the actual average rate of field coverage by the machine to the total time during operation [17]. Therefore,

$$\text{Effective field capacity (ha/h)} = \frac{Total\ area\ covered}{Total\ time\ taken} \qquad (17)$$

#### *2.7.4 Field efficiency*

The field performance evaluation of the developed machine is carried out. Field efficiency is the ratio of effective field capacity and theoretical field capacity. It was determined by the formula in equation 18 [17]. Fig. 3a shows the seedlings loading whereas Fig. 3b demonstrate how the transplanting operation was conducted.

$$\text{Field efficiency} = \frac{effective\ field\ capacity}{Theorotical\ field\ capacity} \times 100\% \quad (18)$$

### 2.8 Performance indices

#### 2.8.1 Hill-to-hill spacing

The hill-to-hill spacing was measured with a steel scale following the transplanting operation by randomly selecting different locations in the field [18].

#### 2.8.2 Planting depth

The seedlings were uprooted immediately after transplanting by holding them close to the soil surface. The distance from that point to the tip of the root was measured to determine the depth of transplanting [19].

#### 2.8.3 Number of seedlings per hill

The number of seedlings per hill was measured directly by counting the number of seedlings picked by the planting finger and transplanted in the field per hill after transplanting [18].

#### 2.8.4 Missing hills

The number of missing hills was counted along with the total number of hills in a square meter area. The percentage missing hill was calculated using the following relationship [18].

$$\text{Missing hill (\%)} = \frac{Number\ of\ missing\ hill\ per\ square\ meter}{Total\ number\ of\ hill\ per\ square\ meter} \times 100 \quad (19)$$

#### 2.8.5 Floating hill

Floating hills are the hills where all the seedlings in a hill are either floating on the surface or just placed on the surface of the mud. Floating hills were counted in a square meter area after transplanting. The percentage of floating hills was calculated using equation 20 [18].

$$\text{Floating hill (\%)} = \frac{Number\ of\ floating\ hill\ per\ square\ meter}{Total\ number\ of\ hill\ per\ square\ meter} \times 100 \quad (20)$$

### 2.9 Experimental Design

The performance test of the developed two-row rice transplanter was conducted at two levels of water depth, and two levels of tillage operation using a strip plot design in a 2×2×3 factorial experiment with three replications in each treatment. The water depth comprised of flooded (D1 = 30 mm) and (D2 = 0 mm), with tillage operation, harrow only (T1) and a combination of plough and harrow (T2).

### 2.10 Data analysis

The data collected from the field trials were analyzed statistically using analysis of variance (ANOVA) and other statistical procedures. SAS Software (v9.0) was used for the ANOVA.

## 3. Results and discussion

### 3.1 Results on machine performance

The average field capacity of the developed rice transplanter was 0.0146 ha/hand, the field efficiency was 55.6% at an average operating speed of 1.50 km/h. The labour required for the machine transplanting was 2 persons (68 man-h/ha) including uprooting and transportation of rice seedlings as against 20 (320 man-h/ha) in the manual hand transplanting. This result demonstrates that using the developed rice transplanter is more cost-effective in terms of labour requirements compared to the hand transplanting method. The response effects of the performance indices hill spacing, hill depth, number of seedlings per hill, missing hill and the floating hill of the machine are discussed in the subsequent sections.

#### 3.1.1 Effect of tillage operation and water depth on hill spacing

The mean values of hill spacing for the different combinations of experimental treatments are presented in Table 1. The distance between the hills varies with tillage operation and water depth. The results obtained from the analysis of variance of the effect of tillage and water depth on hill spacing of the developed transplanter are presented in Table 2. The tillage operation and water depth used on the rice field had a significant effect ($p<0.05$) on the hill spacing. In addition, the interaction effects of the tillage operation and water depth had a significant effect ($p<0.05$) on the hill spacing.

Table 1. Analysis of variance for hill spacing

| Source of Variation | Df | Sum of Square | Mean Square | Calculated F |
|---|---|---|---|---|
| Replication | 2 | 84.67 | 42.33 | |
| Horizontal | 1 | 850.08 | 850.08 | 196.17* |
| tillage | 2 | 8.67 | 4.33 | 0.35 |
| Error a | 1 | 24.08 | 24.08 | 5.56* |
| Vertical depth | 2 | 8.67 | 4.33 | 0.35 |
| Error b | 2 | 252.08 | 252.08 | 20.44* |
| Interaction | 2 | 24.67 | 12.33 | |
| Error c | | | | |
| Total | 11 | 1252.92 | | |

Note: ns = Not Significant, * = Significant at 5% probability level.

The mean effects of tillage and water depth on the hill spacing were further analyzed using LSD presented in Table 2. The result of the tillage operation demonstrated that a significant higher hill spacing of 331 mm was obtained with Tillage operations harrow only (T1) as compared to 314 mm obtained at Tillage combination of plough and harrow (T2). Likewise, the result shows that the water depth flooded at 3 cm (D1) and water depth flooded at 0 cm (D2) are statistically at par. Similar findings were reported elsewhere (6). The inconsistency of hill spacing observed might be due to skidding or slippage of the transplanter because of the depth of puddled soil. This common phenomenon occurs frequently in the field. Behera et al. [20] reported that the plant spacing depended on the puddling methods and was also influenced by the sedimentation period (the period between the end of puddling and the start of transplanting). The higher the sedimentation period, the more accurate plant spacing.

Table 2. LSD on the effect of treatments on hill spacing

| Treatment | Hill Spacing | LSD Mean Ranking |
|---|---|---|
| T1 | 331.333 | A |
| T2 | 314.50 | B |
| D1 | 342.33 | A |
| D2 | 321.5 | A |

Note: means with the same letter are not significantly different.

### 3.1.2 Effect of tillage operation and water depth on seedling per hill

The number of seedlings dispensed per hill varied in different plots. In most cases, 2-3 numbers of seedlings were dispensed per hill. The analysis of variance for the effects of treatments, tillage operations and water depth on the number of plants per hill is presented in Table 3. A non-significant difference ($p>0.05$) was observed in the effect of the tillage operation and the effect of water depth on the developed transplanter. The interaction effects of tillage operation and water depth were also not significant for the number of seedlings per hill. Seyedi [21] and Chaudhary et al. [14] reported similar results.

It is worth noting that the number of seedlings dispensed per hill depended on the seedling density on the tray and the transplanting finger. A single vigour seedling is enough to satisfy the agronomic requirements. To avoid missing hills, a number of seedlings should be more than one [22].

Table 3. Analysis of variance for seedling per hill

| Source of Variation | Df | Sum of Square | Mean Square | Calculated F |
|---|---|---|---|---|
| Replication | 2 | 0.31 | 0.62 | |
| Horizontal | 1 | 0.0833 | 0.083 | 0.25ns |
| tillage | 2 | 0.67 | 0.33 | 1.00 |
| Error a | 1 | 0.75 | 0.75 | 1.00ns |
| Vertical depth | 2 | 0.20 | 0.20 | 1.00 |
| Error b | 2 | 0.083 | 0.083 | 0.25ns |
| Interaction | 2 | 0.67 | 0.33 | |
| Error c | | | | |
| Total | 11 | 2.25 | | |

Note: ns = Not Significant, * = Significant at 5% probability level.

### 3.1.3 Effect of tillage operation and water depth on hill depth

The results obtained from the analysis of variance for the effect of tillage operations and water depth on the hill depth are presented in Table 4. The depth of the hill varied with the water depth. The tillage operations conducted did not significantly ($p>0.05$) affect the hill depth. Significant change ($p<0.05$) was observed for the effect of water depth on the depth of the hill. The interaction effects of tillage operations and water depth were significant ($p<0.05$) on the hill depth. The mean effects of water depth on the hill depth were further analyzed using LSD as presented in Table 5. A non-significant change ($p>0.05$) in the two water depths was observed, with D2 (33 mm) having a higher mean value than D1 (27 mm). Similar assertion was made in previous report [19]. This variation can be traced to the level of field preparation and soil type.

Table 4. Analysis of variance for hill depth

| Source Of Variation | Df | Sum of Square | Mean Square | Calculated F |
|---|---|---|---|---|
| Replication | 2 | 41.17 | 20.58 | |
| Horizontal | 1 | 1.33 | 1.33 | 0.05ns |
| tillage | 2 | 56.17 | 28.08 | 1.21 |
| Error a | 1 | 85.33 | 85.33 | 4.72* |
| Vertical depth | 2 | 36.17 | 18.08 | 0.78 |
| Error b | 2 | 0.0128 | 0.64 | 0.02* |
| Interaction | 2 | 46.5 | 23.25 | |
| Error c | | | | |
| Total | 11 | 266.67 | | |

Note: ns = Not Significant, * = Significant at 5% probability level.

Table 5. LSD on the effect of treatment on hill depth

| Treatment | Hill depth | LSD Mean Ranking |
|---|---|---|
| D2 | 33 | A |
| D1 | 27 | A |

Note: means with the same letter are not significantly different.

*3.1.4 Effect of tillage operation and water depth on missing hill.*

The results obtained from the analysis of variance for the effect of tillage operations and water depth on the percentage of the missing hill are shown in Table 6. The tillage operation has an insignificant effect ($p>0.05$) on the missing hill. Meanwhile, the effect of water depth on the missing hill exhibited a significant change ($p<0.05$) during the transplanting of the rice seedlings. The interaction effect of tillage operations and water depth on the percentage of the missing hill did not differ significantly ($p>0.05$) following the transplanting operation. Further analysis of the mean values of the percentage of missing hills revealed that the effect of water depth on hill spacing was insignificant (Table 7). D2 (36.6%) with a percentage missing hill has a higher mean value than D1 (32%).

Table 6. Analysis of variance for missing hill

| Source of Variation | Df | Sum of Square | Mean Square | Calculated F |
|---|---|---|---|---|
| Replication | 2 | 2.167 | 1.583 | |
| Horizontal | 1 | 1.333 | 1.33 | 0.10ns |
| tillage | 2 | 26.167 | 13.083 | 22.43 |
| Error a | 1 | 65.333 | 65.33 | 21.19* |
| Vertical depth | 2 | 6.1667 | 3.083 | 5.29 |
| Error b | 2 | 1.333 | 1.33 | 2.29ns |
| Interaction | 2 | 1.167 | 0.583 | |
| Error c | | | | |
| Total | 11 | 104.67 | | |

Note: ns = Not Significant, * = Significant at 5% probability level.

Table 7: LSD on the effect of treatment on missing hill

| Treatment | Missing Hill | LSD Mean Ranking |
|---|---|---|
| D2 | 36.667 | A |
| D1 | 32 | A |

Note: means with the same letter are not significantly different.

The transplanted plot exhibited a high missing hill. This might be due to power transmission from the wheel to the transmission mechanism combined with the effects of skidding or slippage of the transplanter due to water height and depth of puddled soil. In this result, the missing hill exceeded the allowable limit of 5% as reported by Alizadeh et al. [23] .

*3.1.5 Effect of tillage operation and water depth on floating hill.*

The results obtained from the analysis of variance for the effect of treatments on the floating hill were presented in Table 8. The result revealed that the floating hill was significantly affected ($p<0.05$) by all the treatments. The interaction of the treatments also exhibited a significant effect ($p<0.05$) on the floating hill. This result conforms to the findings reported by Patil et al. (18).

Table 8. Analysis of variance for floating hill

| Source of Variation | Df | Sum of Square | Mean Square | Calculated F |
|---|---|---|---|---|
| Replication | 2 | 35.167 | 17.583 | |
| Horizontal | 1 | 4.083 | 4.083 | 1.14* |
| tillage | 2 | 7.167 | 3.583 | 0.54 |
| Error a | 1 | 10.083 | 10.083 | 0.95* |
| Vertical | 2 | 21.167 | 10.583 | 1.61 |
| depth | 2 | 80.08 | 80.083 | 12.16* |
| Error b | 2 | 13.167 | 6.583 | |
| Interaction | | | | |
| Error c | | | | |
| Total | 11 | 170.917 | | |

Note: ns = Not Significant, * = Significant at 5% probability level

Table 9. LSD on the effect of treatments on floating hill

| Treatment | Floating Hill | LSD Mean Ranking |
|---|---|---|
| T1 | 51.5 | A |
| T2 | 40.3 | A |
| D1 | 41.833 | A |
| D2 | 40.00 | A |

Note: means with the same letter are not significantly different.

The mean effects of tillage and water depth on the hill spacing were further analyzed using LSD shown in Table 9. The result of the tillage operation established that T1 and T2 are statistically at par. In addition to this, the result of the water depth showed that D1 and D2 are statistically at par.

## 4. Conclusion

A two-row manually operated rice transplanter has been designed for smallholder farmers in Nigeria. Its performance indices were established using rice seedlings. From the performance evaluation carried out on the machine, the results highlighted that the transplanter has great potential in mechanizing the transplanting process of rice hitherto neglected in commercial production due to the lack of the machine at peak season. Based on the results recorded from the performance evaluation, it was concluded that the tillage operation (harrow and combination of harrow and plough) and water depth (3 cm and soil at saturation) have a significant influence on the hill spacing, hill depth and floating hill. Moreover, the percentage of the missing hill (40%) and floating hill (45%) were high during the transplanting operations and therefore need to be reduced. The floating hill increased with rising water depth, with the highest recorded at 45%. The field capacity and efficiency of the transplanter recorded during the performance evaluation were 0.0146 ha/h and 56.8%, respectively.

## Conflict of Interest

The authors declare that they have no conflict of interest

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