



# Modification of Portable Power Tiller for Small Scale Weeding Operation

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## Authors' contributions

This work was carried out in collaboration among all authors. Author AZ, AMEO and USM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors NO and IA managed the analyses of the study. Authors JKA and KA managed the literature searches. All authors read and approved the final manuscript.

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## ABSTRACT

Weeds are unwanted and undesirable plant that interfere with the utilization of land and water resources and adversely affect crop production. After preliminary study, it was found out that power tiller could be adopted for weeding. Therefore, the study aimed at improving its performance through modification of some major component such as: weeding blades and depth gauge. Three sets of pairs of blade gang of four, six and eight were made from 3 mm mild steel sheet metal. The fabrication was carried out at the Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria. The modified machine was evaluated based on weeding efficiency, field capacity, Plant Damage and Fuel consumption in the maize field during 2017/2018 irrigation season at Institute for Agricultural Research, IAR, Ahmadu Bello University, Zaria

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research farm. Four levels of blade types 'B' and three levels of weeding depth 'D' were considered. The field was laid in a 4×3 Randomized Complete Block Design (RCBD) at two (2) Weeks After Sowing (2WAS). DMRT was used for mean separation ran in SAS package. The results showed effects of blade types and weeding depth were significant on the weeding performance of the machine.

*Keywords: Weed; tiller; weeding blade; weeding depth; field capacity.*

## 1. INTRODUCTION

Tillage is a basic operation in farming. It is generally done to create a favourable condition for seed placement and plant growth. These operations include ploughing, harrowing and mechanical destruction of weeds and soil crust, [1]. A power tiller is basically a set of blades (called tines) that are mounted within a wheeled housing and powered by either gasoline engine or an electric motor (tractorsupply.com). Power tiller is otherwise known as cultivator or rotavator. Besides preparing the seedbed, it can be successfully adopted for removal of weeds and stubbles, mixing the manure, fertilizers and crop residues [1]. Weed removal is one of the post planting operation usually carried out by application of chemicals (herbicides), manual uprooting of the weed and mechanical manipulation of the soil.

According to [2] as cited in [3] opined that a farmer using only hand hoe for weeding would find it difficult to escape poverty, since this level of technology tends to perpetuate human drudgery, risk and misery. The operations involved in the crop production cycle include land clearing, land forming/land leveling, tillage, and crop establishment, harvesting and post-harvest operations. Crop establishment is necessary to eliminate the effect of weeds, pests and disease infestation and to provide suitable conditions for optimum yield [3].

A mechanical device to remove the weeds from an agricultural land is known as weeder. A weeder may be manual or animal drawn and tractor mounted or power operated [4]. Mechanical weed control not only uproots the weeds between the crop rows but also keeps the soil surface loose, ensuring better soil aeration and increase water intake capacity, and mechanical weeders perform simultaneous job of weeding and hoeing and can reduce the time spent on weeding (man hours), cost of weeding and drudgery involved in manual weeding. The wider and equal spacing between the plants allow easy operation of mechanical weeders.

This process incorporates the weeds into the soil as green manure crops. It helps to build up soil organic matter and subsequently large and diverse microbial population in the soil. Thus, mechanical weeding operation facilitates the process of aeration in the soil. This in turn mobilizes the micro nutrients required for the healthy growth of the rice plant [5].

The power tiller is capable of removing weeds and harrowing of the soil for viable seed bed. The power tiller's intrinsic characteristic of stocking and clogging of the weeding tines are highly challenging. This inhibits and lowers the weeding efficiency of the machine. The problems with existing power weeder are diverse. The problems of improper design of farm machinery for specific ecological zone, excessive manual labour required to move the machine and high energy requirements to propel the operational components of the tillage machines is higher for soil engaging equipment, also the implications of the unfair competition of imported alternatives, and design and development of some prototypes that are not yet perfected among other factors constitute the major problems in farm tillage machinery development in Nigeria [6]. There is an increasing interest in the use of mechanical intra row weeders because of concern over environmental degradation and a growing demand for organically produced food [7]. Low weeding efficiency attributed to the power tiller since it is not primarily designed for weeding operation, attracted interest in design and fabrication of new weeding blades and depth gauge for effective weeding. The tiller is a light weight machine, compacted and design to suit easy mobility and operator convenience. With the incorporation of depth wheel which controls the depth of the cut of the weed, this eliminates the challenge of stocking during operation. Also, with the adoption and design of "L" shaped weeding blade as a weeding unit, will help to improve weeding and better soil engagement of the tiller. The aim of this research is to carry out the modification and performance evaluation of portable Power tiller for effective weeding operation.

## 2. MATERIALS AND METHODS

The concept of the research was targeted at modifying the powered tiller as weeding tool used on flat weeding. The modification of the powered tiller entailed design and fabrication of weeding unit and depth gauge component of the tiller. Evaluation procedures are presented in the course of the headings.

### 2.1 Machine Component Modification

Two components of the machine were modified. These were; the weeding unit and the depth gauge. The weeding unit which was basically set of blade gangs (in 4, 6 and 8), modified for improve weeding and soil engagement. The depth gauge was incorporated for effective gauging of depth of cut during weeding operation, ease of mobility and to prevent the stocking of the weeding unit.

### 2.2 Materials

The following materials were employed in the fabrication of the modified components of the power tiller. These fabrication materials were mild steel Sheet metal, Bolts and nuts and mild steel pipe. These materials were selected based on availability and affordability. Also, instrumentations employed in the evaluation were stopwatch, metre rule of 100 m, tachometer and measuring cylinder.

### 2.3 Design Consideration

In the design of the weeding unit, factors associated with ease of operations, machine and plant were considered. These factors include,

- The radius of the blade from the centre of the shaft was chosen as 9 cm. This was selected to check the blades against making contact with the mud flap during weeding operation.
- The machine is to be operated within inter row space of flat field only.
- The depth of cut of 4 cm and effective width of cut of 12 cm was observed.
- According to [8], the walking speed of a healthy man was 1 km/hr equivalent to 0.28 m/s.
- According to [9], the minimum speed of revolutions required for weeding was 150 rpm.
- The transmission efficiency of the operation was assumed to be 82% as given by [4].

### 2.4 Design of Components

The design of components entails the design of shaft, determination of power required for weeding and transportation of the machine, selection of the modified weeding blades and depth gauge components.

#### 2.4.1 Selection of the modified weeding blades and depth gauge

Plate 1 shows the power tiller with the existing weeding blades. The “L” shaped weeding blade were selected as replacement for the modified power tiller tines. The blades were arranged in four, six and eight gangs, made of 3 mm mild steel sheet metal as shown in Plate 2, 3, and 4. The depth gauge made from mild steel sheet metal incorporated and adjustable to range of 1 cm to 3 cm.



Plate 1. The power tiller with existing blades



Plate 2. Four Blades Type



**Plate 3. Six blades type**



**Plate 4. Eight blades type**

### 2.4.2 Design of shaft

The power tiller was coupled with a solid shaft, hence a hollow shaft which housed the blades and was designed using Equation 2.1.

According to [10], the hollow shaft size was computed as follows

$$(d_o^3 - d_i^3) = \frac{16M_t}{\pi\tau} \quad (2.1)$$

where,  $d_o$  = outer shaft diameter (mm)  
 $d_i$  = inner shaft diameter (12 mm)  
 $M_t$  = torque (Nm)  
 $\tau$  = allowable shear stress (N/m<sup>2</sup>)  
 $\pi$  = constant (3.142)

The torque developed ( $M_t$ ) during weeding operation was determined by;

$$M_t = F \times R \quad (2.2)$$

where,  $M_t$  = Torque developed, Nm  
 $F$  = tangential force, N  
 $R$  = rolling radius of weeding blades (0.068 m)

The tangential force is the combine effect of force required to remove the weed and the thrust necessary to move the weeder. Therefore, tangential force  $F$  was determined as follows;

$$F = F_w + F_{th} \quad (2.3)$$

where,  $F$  = tangential force, N  
 $F_w$  = force required for removing the weed (247.2 N)  
 $F_{th}$  = thrust (61.2 N)

The tiller engine is coupled with a 12 mm solid shaft. Therefore, the outer shaft size  $d_o$  of 14 mm was computed and sufficient for the design.

### 2.4.3 Power required for weeding

Power required for weeding operation is the combine effect of the power required to remove the weed and the power required due to thrust by machine as observed in the nature of operation the Power Tiller.

#### 2.4.3.1 Power required by the blades to remove the weeds

Power required by the blades to remove the weeds ( $P_w$ ) was adopted after [6], as expressed in equation 2.4.

$$P_w = \frac{S_R \times d \times w \times v}{75} \quad (2.4)$$

where,  $P_w$  = power required by the blade to remove the weed, kW  
 $S_R$  = soil resistance, kg/cm<sup>2</sup>  
 $d$  = depth of cut, cm  
 $w$  = effective width of cut, cm  
 $v$  = linear velocity of the weeding blade at the point of contact with the soil, m/s

Following [6], the determination of actual power required to remove the weed was as follows

$$P_{aw} = \frac{P_w}{\eta} \quad (2.5)$$

where,  $P_{aw}$  = actual power required to remove weed, kW  
 $\eta$  = transmission efficiency (0.82)  
 $P_w$  = theoretical power required to remove weed, kW

A blade from each gang cut the soil simultaneously, hence total of two (2) blades cut the soil with effective width of cut of  $2 \times 3$  cm (6 cm).

The power required to remove the weed  $P_w$  was computed using equation 2.4 as 0.43 kW.

Thereafter, the actual power  $P_{aw}$  required to remove the weed was determined using equation 2.5 as 0.53 kW.

#### 2.4.3.2 Power required for the thrust

The power required due to thrust by the machine rotational weeding blade was expressed as follows.

According to [11], assuming a pneumatic wheel and the thrust  $F$  was expressed as

$$F_{th} = [0.75(1 - e^{-0.3C_n S})]W \quad (2.6)$$

where,  $F_{th}$  = thrust (N)  
 $C_n$  = cone Factor (unitless)  
 $S$  = wheel slip (0.1)  
 $W$  = machine weight (130 N)

The cone factor  $C_n$  was determined by the following [11]

$$C_n = \frac{Clbd}{W} \quad (2.7)$$

where,  $Cl$  = cone index  
 $b$  = wheel width (6 cm)  
 $d$  = overall depth of the wheel (12 cm).  
 $W$  = machine weight (130 N)

The power required due to thrust  $P_{th}$  was expressed after [12]

$$P_{th} = F_{th} \times V \quad (2.8)$$

where,  $F_{th}$  = thrust (64.35 N)  
 $V$  = speed of the weeding gang (1.73 m/s)

Therefore, the total power required for the weeding operation was computed as 0.64 kW.

The power tiller's engine has the rated power of 1.2 kW which was suitable for the weeding operation.

#### 2.4.4 Depth gauge

The contact wheel was primarily designed to withstand the drudges due to transportation of the machine during weeding operation. The gauge was made with mild steel sheet metal.

The power required to transport the machine during operation was determined as follows [11].

$$P_t = T_f \times V \quad (2.9)$$

where,  $P_t$  = power required to transport the machine, kW  
 $T_f$  = towed force (N)  
 $V$  = operator linear speed

The towed force  $T_f$  for a wheel (assuming pneumatic) is determined from the dimensional analysis as stated by [11].

$$T_f = \left(\frac{1.2}{C_n} + 0.04\right)W \quad (2.10)$$

where,  $C_n$  = cone factor  
 $W$  = weight of the machine  
 $T_f$  = towed force (N)

### 2.5 Performance Evaluation

Performance indicators evaluated include;

- i. Weeding efficiency,  $W_e$
- ii. Field capacity,  $C_e$
- iii. Plant damage,  $P_d$
- iv. Fuel consumption rate,  $F_{cr}$

#### 2.5.1 Weeding efficiency

Weeding efficiency is the ratio of number of weeds removed to the number if weed count before weeding in the quadrant. This was determined using the following equation ([6] and [13]).

$$W_e = \frac{(W_1 - W_2)}{W_1} \quad (2.11)$$

where,  $W_e$  = weeding efficiency (%)  
 $W_1$  = weed count before weeding in the quadrant  
 $W_2$  = weed count after weeding in the quadrant

#### 2.5.2 Effective field capacity

This is the area of the quadrant covered by the modified tiller during weeding operation in a specific time. According to [5], effective field capacity was calculated using the following equation.

$$C_e = \frac{A}{T \times 10000} \quad (2.12)$$

where,  $C_e$  = effective field capacity (ha/hr)  
 $A$  = area of the quadrant ( $m^2$ )

T = total time of weeding the quadrant (hr)

### 2.5.3 Plant damage

Plant damage is the measure of damage on crop plants during weeding operation. Plant damage was observed in terms of buried plants by soil mass as well as cutting of plant leaves by rotating action of weeding blades.

Number of plants in the quadrant before and after weeding was observed and the plant damage 'Q' was calculated by using the relationship expressed in equation 3.3 [13].

$$Q (\%) = \left[ 1 - \left( \frac{q}{p} \right) \right] \times 100 \quad (2.13)$$

where, Q = plant damage (%)

p = Number of total plants in the quadrant before weeding

q = Number of undamaged plants in the quadrant after weeding

### 2.5.4 Fuel consumption rate

Fuel consumption rate is the amount of fuel used per unit time. The fuel consumption rate per tillage operation was determined using refilling (volume) method. A calibrated cylinder was used for refilling the fuel, to quantify the fuel used. The fuel consumption rate was determined using the following relationship [14].

$$F_{cr} = \frac{Q_f}{T} \quad (2.14)$$

where;  $F_{cr}$  = fuel consumption rate (l/h)

$Q_f$  = Quantity of fuel consumed (l)

T = time taken (h)

## 2.6 Experimental Setup

The performance indicators were determined by considering the independent variables; weeding depth D and weeding blade type B. Three (3) levels of weeding depth D ( $D_1 = 1$  cm,  $D_2 = 2$  cm and  $D_3 = 3$  cm) were selected. Likewise, four sets of weeding blade B ( $B_1 = 4$  blades,  $B_2 = 6$  blades,  $B_3 = 8$  blades) along with the existing blade  $B_4$  were evaluated. The experiment was replicated thrice. The weeding operation was carried out on a maize field at two weeks after sowing 2WAS. The combination of performance parameters was tested. Each combination of parameters was tested at a quadrant of 1 m by 0.75 m. The experiment was laid in a randomized

complete block design. Analysis of variance ANOVA was adopted for the analysis of the data obtains from the interaction of the independent variables. Statistical Analysis System SAS Software was employed for the analysis.

## 3. RESULTS AND DISCUSSION

### 3.1 Weeding Efficiency

The result of analysis of variance (ANOVA) for weeding efficiency shows that the effect of tillage types, blade types and weeding depths were highly significant at 2WAS. The interaction effect of blade types and weeding depths were highly significant.

Table 1 shows the interaction effect of blade types and weeding depth. The mean weeding efficiency increased with increase in number of blades for all weeding depths at all the weed growth stages and were statistically different with existing blade type. Mean weeding efficiency increased with increase in weeding depth for four, six and eight blade types and decreased for existing blade type. Across the weeding stages, the highest mean weeding efficiency of 87.8% recorded for six blades types at 3 cm and least efficiency of 53.2 % recorded for existing blade types at depth 3 cm. This agrees with [4] with highest weeding efficiency of 88.62% for a six blades types, also agrees with [15] and [5] of 88% and 87.7% weeding efficiency respectively.

### 3.2 Field Capacity

The result of analysis of variance (ANOVA) of effect of blade types and weeding depths on the field capacity at two weeks after sowing. The result shows that effect of blade type and weeding depth were highly significant. The interaction effects were highly significant. Tables 2 indicated that the mean field capacity increased with increase in the number of blade types at a particular weeding depth. This attributes to increasing contact of the blades with the soil. The highest mean field capacity of 0.00712 ha/hr was recorded when existing blades was used at 3 cm. Generally, the highest mean field capacity of 0.00712 ha/hr recorded was very low compared with [4] of 0.054 ha/hr, [15] of 0.02 ha/hr, [13] of 0.050 ha/hr, [16] of 0.028 ha/hr and [5] of 0.026 ha/hr. The low mean field capacity may be attributed to the low width of cut of the machine for weeding operation.

### 3.3 Plant Damage

The results of analysis of variance (ANOVA) on percentage plant damage at two weeks after sowing (2WAS) shows that effect of blade types and weeding depth on percent plant damage was significant. The interactions effect between blade types and weeding depth was not significant. Tables 3 and 4 shows the effect of blade types and weeding depths on percentage plant damage. Highest percentage plant damage of

19.5% was recorded for eight blades type which was statistically the same with six and existing blade type but statistically different from four blade type. The percentage plant damage increases with increased in number of blades. Percentage plant damage decreased with increase in weeding depth with least recorded damage of 9.0%. Damage to plant was higher at the lighter depth of 1 cm because of the tenderness of plant since the plant is young and susceptible to rupture by slightest force.

**Table 1. Interaction effect of blade types and weeding depth on weeding efficiency**

Mean Weeding efficiency 2 weeks after sowing (%)				
Treatment	Blade type (B)			
	4	6	8	Existing
<b>Weeding depth (D) cm</b>				
1	65.6d	75.8c	82.8ab	56.1e
2	78.4bc	80.7bc	86.4a	54.9e
3	77.4bc	87.8a	87.0a	53.2e
SE±	1.792			

Mean followed by same letter(s) in the same column are not different statistically at P=0.05 using DMRT.

**Table 2. Interaction between blade types and weeding depth on field capacity**

Mean field capacity 2 weeks after sowing (ha/hr)				
Treatment	Blade type (B)			
	4	6	8	Existing
<b>Weeding depth (D) cm</b>				
1	0.00450g	0.00510ef	0.00602c	0.00705ab
2	0.00468fg	0.00545de	0.00527cd	0.00663ab
3	0.00450g	0.00572cd	0.00657b	0.00712a
SE±	0.000182			

Mean followed by same letter(s) in the same column are not different statistically at P=0.05 using DMRT.

**Table 3. Effect of blade type on percentage plant damage**

Treatment	2WAS
<b>Blade type (B)</b>	
4	9.1b
6	14.8ab
8	19.5a
Existing	13.5ab
SE±	2.355

Mean followed by same letter(s) in the same column are not different statistically at P=0.05 using DMRT.

**Table 4. Effect of weeding depth on percentage plant damage**

Treatment	2WAS
<b>Weeding depth (D) cm</b>	
1	17.3a
2	16.4a
3	9.0b
SE±	2.039

Mean followed by same letter in the same column are not different statistically at P=0.05 using DMRT.



Plate 5. The power tiller with modified weeding blades and depth gauge

### 3.4 Fuel Consumption

Highest fuel consumption rate of 0.45 l/hr was recorded. This is lower than the maximum fuel consumption rate of 0.67 l/hr recorded by [4] at two weeks after sowing (2WAS). The variation in fuel consumption rate may be attributed to differences in crop type of maize and rice.

### 4. CONCLUSION

The power tiller was modified with a set of weeding blades specifically four, six and eight gangs and depth gauge. It is therefore concluded that weeding using six or eight blades type at the average weeding depth of 2 cm result in maximum weeding performance. With these combinations, the best machine performance was recommended based on mean weeding efficiency, field capacity and least percentage plant damage were 87.7%, 0.00712 ha/hr and 9.0% respectively were recorded.

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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