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Development And Performance Evaluation of A Push – Type Mechanical Row Weeder

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ABSTRACT: Weed competes with crop plant for soil nutrients, moisture, light and space, thereby reducing crop production yield and increasing cost of maintaining the farm. Many methods of weed control such as chemical, cultural and biological have been tried with varied degrees of success but environmental impact of herbicides made chemical method of weed control unsustainable and the drudgery involve in manual method of weed control limits the size of farm of an individual farmer in Nigeria. A push type mechanical row crop weeder was developed in Ladoke Akintola University of Technology, Ogbomoso in Nigeria, to alleviate the drudgery of subsistence farmers, increase production and hence reducing poverty. The weeder was developed and fabricated from locally sourced materials and tested on a mapped out plot of 10 m x 5 m area. The machine consists of tines and circular disc (mounted on a shaft), transmission system, frame, pneumatic wheels and was powered with a 5 Hp petrol engine. The height of cut of the machine is adjustable, thus the machine operates as a mower when cutting height is 2 - 4cm above the ground level, but works as a weeder 2 cm below the ground with an effective width of cut 300 mm. The weeding efficiency and the field capacity of the designed machine were 63% and 0.03 ha/h respectively and the cost of the prototype machine estimated at ₦55,200 was less compare with the other row crop weeders fabricated locally. The developed machine is simple, required little or no maintenance skill and useful for small to medium scale farm holders. It will also reduce drudgery

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1. INTRODUCTION

Manual weeding requires huge labour force. In Nigeria, this operation is mostly performed with cutlass or hoe that requires high labour input, very tedious and it is a time-consuming process. Weeds have very fast growth rates compared to other crops, and if not treated and managed, they may dominate the field. Weeds affect crop yield due to competition to acquire plant nutrients and resources (Slaughter *et al*., 2008; Weide *et al.*, 2008). Weed management is a strategy that makes a desired plant population successful in a particular agro ecosystem using knowledge of the ecology of the undesired plants, which is the weeds (Ghersa *et al*., 2000).

Oni (1990) reported that 50 to 70% of yield reduction is caused by poor weed control. Weeding and hoeing is generally done 15 to 20 days after sowing. The weed should be controlled and eliminated at their early stage. Depending upon the weed density, 20 to 30 percent loss in grain yield is quite usual which might increase up to 80 percent if adequate crop management practice is not observed. Rice and groundnut are very sensitive to weed as reported by Goel, *et al* (2008). The use of herbicides adversely leads to desert encroachment and intensive application of pesticides contributes significantly to environmental pollution (Busari, 1996; Gobor and Lambers, 2007).

Presently, there are many types of weeders available from simple to complex and motorized weeders. Several innovative and cost effective designs were developed and experimented according to the requirements of the farmers and soil conditions. Efforts are still on to reduce the drudgery in weeding operation (Thiyagarajan, *et. al* , 2006).

Utilization of hand tool technology is one of the major problems of poverty in the rural areas. Nganilwa *et al*. (2003) 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 most common methods of weed control are mechanical, chemical, biological and cultural methods. Out of these four methods, mechanical weeding either by hand tools or mechanical weeders are most effective in both dry land and wet land. Mechanical weed control not only uproots the weeds between the crop rows but also keeps the soil surface loose, ensuring better soil aeration and water intake capacity.

In Nigeria, farmer spent so much money for controlling weeds every year, in the production of major crops. Poor weed control leads to loss of several tones of major food grains every year. Therefore, timely weeding is very much essential for a good yield and this can only be achieved by using mechanical weeders which perform simultaneous job of weeding and tilling that reduce the time spent on weeding (man hour), cost of weeding and drudgery involved in manual weeding. Weeds can cause several damages to the farming enterprise. These include: decrease in crop yield, impairment of crop quality, harboring of plant pests and diseases, increase in irrigation costs, injury to livestock and decrease in land values, thus the objective was to design and fabricate a push type row weeder fitted with a guard using locally available materials.

II. MATERIALS AND METHODS

2.1 Description of the Machine and its Component Parts:

The weeder consists of the following component parts as shown in Fig.1; a 5 hp petrol engine, three ground wheels (pneumatic), frame and handle. The weeder is manually-operated and the power to the rotary hoe is supplied from the engine through belt and pulley arrangement. The motion of the weeding disc at any point on the surface of a mechanical weeder travels through a trochoidal or cycloidal path depending on the distance of the point from the rotor axis (radius).

2.2 Method and Material Selection

The push type mechanical weeder puts into consideration the basic engineering principles and the properties of the soil where the cutter or tines will operate. The maximum power output from the machine combined with functional requirements and cost are combined to achieve the designed objectives. The designs parameters were established after reviewing some literatures and employing the assessed engineering properties of soil on which destruction of weeds will take place. Power transfer device is belt and pulley which the operators are familiar with in terms of use, adjustments, repairs and maintenance.

The following materials/components were used for the development of the mechanical weeder: A 5hp-petrol engine (Prime Mover), three ground wheels of 300 mm diameter (pneumatic i.e. Air-filled), angle bar for frame (50mm x 50mm), hollow pipe for handle (25mm in diameter), belt and pulley, bearings, plate for guard (1.5mm in thickness), iron rod (8mm in diameter) and bolt and nuts.

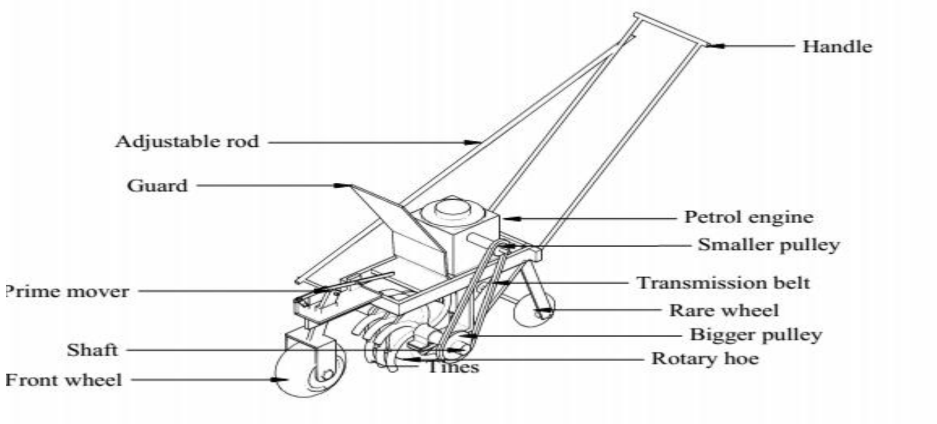

Fig 1: Isometric View of the Push-Type Mechanical Row Weeder

2.3 Power Unit

The power was transmitted from petrol engine (5hp) through the rotor to the pulley on the engine. The power transmitted via pulley belt arrangement (vertical arrangement to the petrol engine) was connected to the rotary hoe.

2.4 Machine Design Calculation

The machine design calculations was by the use of first principle of mechanics to determine the force required by the frame and the tine, the bending and torsional moment of the machine shaft size and other component parts. The component parts and assembly drawing of the machine was carried out, and are shown in Fig. 2 and 3 in the appendix. Fabrication works which include metal cutting, turning, bending, shaping and welding was carried out at the workshop with locally available material. The machine was tested at average human being speed on loamy soil and different position on the soil.

2.4.1 Design consideration

In other to design an efficient mechanical weeder, important designs requirements to be considered are; availability and suitability of the material to be used. Other factors include;

1. The density and the condition of the weed.
2. Soil physical characteristics (soil moisture content, bulk density).
3. The characteristics of the interface between soil and the soil acting elements of the weeder.
4. Soil implement interface (width of cut, depth of cut, soil cohesion).

2.4.2 Design assumptions

The assumptions in the design of the mechanical weeder were made with reference to the field conditions, machine capacity and energy required to power it. The machine was powered by a 5-hp internal combustion engine. Belt and Pulley arrangement was employed for transmission of power. Engine speed, N_1 = 3600 rpm, diameter of pulley, D_1 = 50 mm, diameter of pulley, D_2 on shaft = 50 x 6 = 300 mm, pulley ratio = 1:6, shaft speed, N_2 = 600 rpm, maximum soil resistance value = 1.5 kgf/cm^2, coefficient of friction = 0.1, depth of cut of rotary hoe, d cm (15 cm) and w = effective width of cut of rotary hoe, cm (50 cm).

2.5 Design Calculations

The following calculations were determined based on the principle of machine design;

2.5.1Belt drive

The factors considered for belt selection are: power rating of the prime mover, length of belt, the centre distance, and correction factor for belt and angle of wrap. The centre distance denotes the centre between the two pulleys (engine pulley and machine pulley). It is determined by equation 1, the pitch length is given by equation 2 and the velocity of belt, V is given by equation 3.3.

$$C \geq \frac{D_1 + D_2}{2} + 50 \text{ mm} \qquad 1$$

$$L = 2C + \frac{\Pi}{2}(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4C} \qquad 2$$

$$\text{Velocity of belt} = \frac{\Pi \text{ x minimum pitch diameter x speed}}{60} \qquad 3$$

The centre distance, $C \geq 225$ mm and C = 250 mm. The pitch length, L is estimated as 1112.4 mm and a *V*-belt type of 1210mm was preferred. The calculated velocity of belt, V evaluated as 9.43 m/s.

2.5.2 The main mechanical weeder shaft

Shaft design consists primarily of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions. During weeding process the shaft is subjected to torsion, bending and axial loads. These were estimated by using Equations 4 – 6.

$$\tau_{xy} = (16M_t)/(\pi d^3) \qquad 4$$

$$S_b = (32M_b)/(\pi d^3) \qquad 5$$

$$d^3 = \frac{16}{\pi} S_a[(K_b M_b)^2 + (K_t M_t)^2]^{½} \qquad 6$$

Where,

τ_{xy} = torsional shear stress, N/m^2

Mb = bending moment; Nm

Mt = torsional moment, Nm

d =diameter of shaft, m

S_a = axial stress, N/m^2

S_b = bending stress, N/m^2

K_b = combined shock and fatigue factor applied to bending moment

K_t = combined shock and fatigue factor applied to torsional moment

The estimated shaft diameter of the mechanical weeder was 19mm. The main shaft of the mechanical weeder is illustrated in fig 3.2

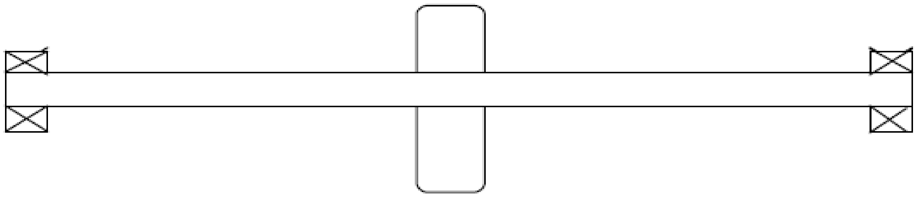

Fig 3.2: Free Sketch of the Shaft with Support at Both Ends

2.5.3 Assessment of power required

Power required to dig the soil, Pd was determined by using equation 7 and Total power required is calculated from equation 8.

$P_d = S_R * d_1 * w * v$ 7

Total power, $P_t = P_d/ή$ 8

Where,

d_1 = depth of cut, cm, (5 cm)

w = effective width of cut, cm, (50 cm)

S_R = soil resistance, kgf/cm2, (1.5 kgf/cm2)

P_d = power required to dig the soil

ή = efficiency of transmission, % (75 %)

The estimated power required to dig the soil, Pd was 3.5 hp and the total power required as 4.23 hp, thus, a prime mover of 5 hp was required for this weeder.

2.5.4 Determination of length of tines

Each hoe consists of six tines of equal length. Length of each tine (Lt) was determined by considering sector ABC, length of arc AB, which form the curved tine may be calculated by equation 9

Length of arc AB = $(\theta_1 - \theta_2) + \frac{2\pi r\theta}{360^0}$ 9

Where,

$r = \frac{3}{5}R$

r = radius of curvature, mm

R = Outer wheel radius, mm

$\theta = 90^0$

θ_1 = outer wheel diameter, mm

θ_2 = disk hole diameter, mm

Length of tine for ϕ160mm hoe

$R = \frac{130}{2}$ = 65mm

$r = \frac{3}{5}R$ = 39mm

$\theta = 90^0$

:. AB = $\frac{2\pi \text{ x } 39 \text{ x } 90^0}{360^0}$ = 61.3mm

:. Length = $(\theta_1 - \theta_2) + \frac{2\pi r\theta}{360^0} = 138^0$

2.5.5 Handle design and ergonomics

Handle is a sensitive part of this machine. It is the point of application of propelling force. Engineering designs and ergonomics considerations of a handle becomes imperative for better performance. Ojo (1994) ascertained the average hip height to be 940 mm. The information was used to determine the length of the handle where the farmer/ operator can position his hands without bending down. The handle was positioned above the hip height so as to avoid the bending posture; this was reported by Nwuba, (1982) to have contributed mostly to the high energy demand of most manually operated hoes. Hence, this weeder handle was considered good at 1000 mm height above the ground.

2.5.6 Cutting geometry

Tines are the working part of the rotary hoe. They break and loosen the soil, uproot the plant and displace the soil particles. The plant material is uprooted as the disk which carries the tines rotates. The tine has a velocity component relative to the weeder and a component due to the forward speed of the weeder. The vector sum of these two components gives the tine velocity relative to the ground. In general, the relationship between the rake, bevel and clearance angles is presented by equation 10.

$$\phi_{rk} + \phi_{bk} + \phi_{ck} = 90^0 \quad (10)$$

Where,

ϕ_{rk} = rake angle
ϕ_{bk} = bevel angle
ϕ_{ck} = clearance angle

2.5.7 Weeding force

Draft data for tillage implements are reported as the force required in the horizontal direction of travel (ASAE D230, 1990). Only functional draft (soil and crop resistance) is reported. Total implement draft was obtained by adding the rolling resistance (*RR*) of the transport wheels. Draft per unit effective width at typical field speeds for row cultivator is given by ASAE standards as:

$$115+230d_3 \text{ N/m} \quad (11)$$

Where,
d_3= tool depth, cm
The average of the two extreme values, draft per meter at 2cm depth (by design) is

$$[\frac{115+230}{2}] \times 2 = 345 \text{ N/m}$$

Width of weeding tool is 40 cm (by design).
Hence, draft of implement = 345 x 0.4 = 138N
The rolling resistance (*RR*) is given by ASAE (1990) as

$$RR = \frac{CIb\, d_4}{C_n} [\frac{1.2}{C_n} + 0.04] \quad (12)$$

Where,

C_n = dimensionless ratio which is a function of the cone index (CI) for the soil
b = unloaded tyre section width
d_4 = unloaded overall tyre diameter
For tilled agricultural drive wheel tyres, bd/w = 0.25 on typical soil surface, CI = 80, C_n = 20
Where,

W = dynamic load in Newton normal to the soil surface and is given as

$$W = \frac{CIbd}{C_n} \quad (13)$$

For wheels on the weeder, b = 0.0738, d = 0.0355m
Substitute these values into equation (37),

$$RR = \frac{80 \times 0.0738 \times 0.0355}{20} [\frac{1.2}{20} + 0.04] = 1.048 \times 10^{-3} \text{ N}$$

RR for the 3 wheels = 4.19×10^{-3} N
:. Total draft = 138 + (4.19×10^{-3} N) = 138.004 N

2.6 Performance evaluation

The performance evaluation of the fabricated mechanical weeder was conducted at the field behind the Department of Agricultural Engineering laboratory, LAUTECH, Ogbomoso, Nigeria. About 5 m x 10 m plot of land was mapped out. The mechanical weeder was tested on the mapped out plot to determine the weeding index, weeding efficiency and field capacity.

Weeding index is a ratio between the number of weeds removed by a weeder and the number present in a unit area and is expressed as a percentage (Rangasamy, *et al.,* 1993). The time taken to perform this operation was noted. Equation 14 was used to calculate weeding index.

$$\text{Weeding index,} \quad I_w = \frac{w_1 - w_2}{w_1} \quad (14)$$

Where,
W1 = Total weight of weeds,
W2 = Weight of weeds after weeding
I_W = Weeding Index

The weeding efficiency was determined by using equation 15

$$\text{Weeding efficiency, } \eta = \frac{w_1 - w_2}{w_1} \times 100\% \quad (15)$$

Where,
W1 = Total weight of weeds,
W2 = Weight of weeds after weeding,

η = weeding Efficiency

The mechanical weeder was tested on the same plots to determine the field capacity of the machine. Field capacity is the amount of area that a weeder can cover per unit time as shown in equation 16.

$$\text{Field capacity (ha/h)} = \frac{3600}{t} \times \frac{A}{10000} \qquad 16$$

III. RESULTS AND DISCUSSIONS

After the performance evaluation of the push type row weeder, the weeding index at different weeding rows was found to be in the range of 0.614 to 0.645 as shown in Table 1, where Row 1 and 5 have the least weeding index while the higher weeding index were obtained in Row 2, 3 and 4 respectively. It was observed that the highest weeding index of 0.645 was obtained with developed mechanical weeder at the fourth row; this may be due to the height of the weeds in that particular row and topography of the land. The least weeding index of 0.614 was found at first row and this may be due to hardness of the soil in that row and density of weeds.

In row 1 and row 5 where the weeds are scattered (i.e. low weed density) and short in height, the amount of weeds that were removed by the mechanical weeder was low compared with row 2, 3 and 4 respectively where the weeds are not scattered, this shows that from Table 1, the cutting efficiency is affected by the weed height, density and hardness of the soil. The soil hardness results from low moisture content of the soil because the designed weeder was tested during the dry season which brings about low weeding efficiency in row 1 and 5.

Table 2 shows the effect of forward speeds and effective width of cut of the machine on weeding efficiency and field capacity of the mechanical weeder. From Table 2, it was observed that Row 1 has the highest forward speed of 0.287 m/s with an effective width of cut of 0.3 m and this resulted into low weeding efficiency in that particular row and high field capacity of 0.031 ha/h and this may be due to speed of operator.

The least forward speed of 0.267m/s was obtained in Row 2 which resulted into high weeding efficiency and low field capacity of 0.029ha/h. The results show that weeding efficiency was consistently higher with decrease in forward speed and consistently lower with increase in forward speed. Although, higher forward speed enhances machine field capacity, duration for weed removal is reduced as the machine browse through the field. Average forward speeds of 0.278 m/s and effective width of cut of 0.3m resulted in weeding efficiency of 63% and field capacity of 0.03ha/h

The machine has an effective width of cut 0.3 m and a field capacity of 0.03 ha/h as shown in table 2. The average field efficiency was 63%. In 8hours working day, the push type row weeder will have a field capacity of 0.24ha/h. Thus four operators with four weeders would conveniently weed one hectare (1ha) of farmland in one day. The mechanical weeder performed best as a mower between cutting heights of 2 - 4 cm and works well as a weeder 2 cm below ground level. Some cultural practices, which involve ridges and heaps, are not well suited for the use of the machine. However, conventional tillage, minimum tillage and zero tillage are well suited for the use of weeding machine.

The cost of the prototype machine was estimated at N55,200 and suitably compare with other row crop weeders that were fabricated locally such as Olukunle and Oguntunde (2006) who developed a similar weeder estimated at N65,000.

Table 1: Weeding density before and after weeding

Rows	Weight of weeds			Weeding index	
	Total weed weightW_1 (g)	After weeding W_2(g)	Weeds removed (g)	$(W_1-W_2)/W_1$	
1	424.4	163.7	260.7	0.614	
2	368.7	134.8	233.9	0.634	
3	382.1	141.6	240.5	0.629	
4	387.3	137.4	249.9	0.645	
5	400.9	150.1	250.8	0.626	
Total	1963.4	727.6	1235.8	3.148	
Mean	392.68	145.52	247.16	0.63	

Table 2: Time taken, Distance moved and Forward speed

Rows	Distance moved (m)	Time taken (s)	Forward speed (m/s)	Width of cut (m)
1	10	34.8	0.287	0.3
2	10	37.4	0.267	0.3
3	10	35.6	0.280	0.3
4	10	36.2	0.276	0.3
5	10	35.9	0.278	0.3
Total	50	179.9	1.388	1.5
Mean	10	35.98	0.278	0.3

IV. CONCLUSIONS

The designed push type row weeder is easy to operate, less expensive and require little or no maintenance practice or skill. The designed weeder was moderately light in weight thus suitable to be operated by one person/operator and could be affordable by most peasant farmers.

The machine though designed as a weeder, could be adapted as a mower in tree crop plantation such as; cocoa, cashew, coffee, and for a variety of weeds thus the machine performed as a weeder and as well as a mower. It works as a mower when cutting height is between 2 cm and 4 cm; however it works well as a weeder with cutting height of 2 cm below the ground level. The machine performed effectively with an efficiency of 63% at forward speeds of 0.278 m/s with an effective width of cut of 0.3m and a field capacity of 0.03 ha/h.

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APPENDIX

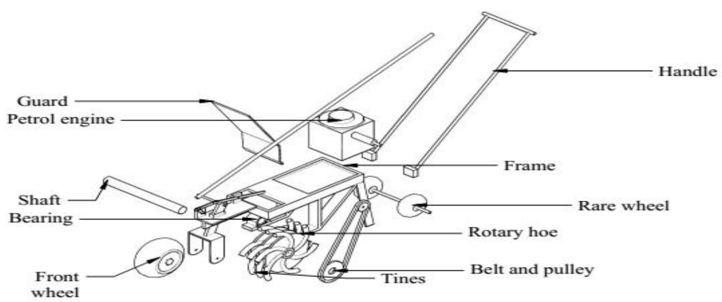

FIG. 2: Exploded View of the Push- Type Mechanical Row Weeder

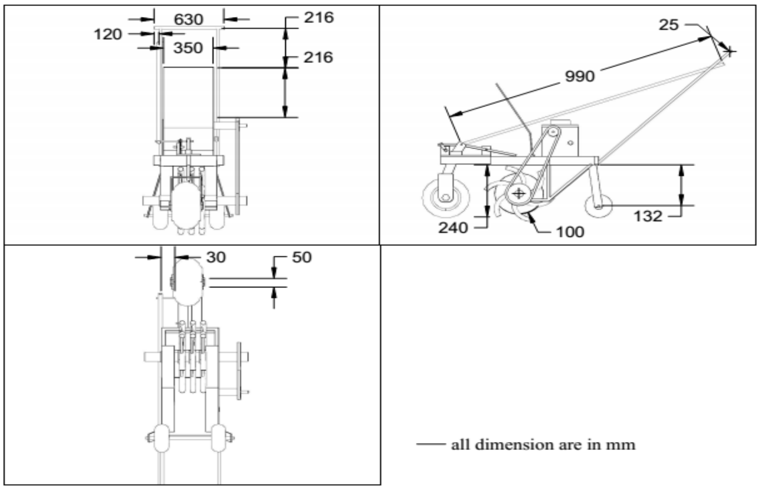

FIG. 3: Autographic drawing of the Push- Type Row Weeder

PLATE 1: Pictorial View of the Push- Type Mechanical Row Weeder

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