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Design, Fabrication, and Testing of a Horizontal Weeding Machine

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ABSTRACT

This research work focused on the design, fabrication and performance evaluation of a horizontal weeding machine which is powered by a 6 hp petrol engine. The research work was aimed at reducing cost, labour, stress and time wastage involved in the weeding operation on the farm. The machine consists of frame, pulleys, belt, bearings, the petrol engine, depth adjuster, set of weeding blades, frame support, protector, and wheels. The machine was fabricated from locally sourced materials, which makes it cheap and easily affordable and also easy and cheaper to maintain. The machine was tested at the soil moisture content level of 16 % and operation depth of 35 mm. The result revealed that the weeding efficiency increased with an increase in blade rotational speed from 1000 rpm to 2500 rpm. Also, increasing the operator's speed from 0.54 km/hr to 1.26 km/hr increased the weeding efficiency from 90.8% to 97.6% and then decreased to 52.3% with further increased in speed to 1.62 km/hr. The effective machine capacity increased with increasing operator's speed from 0.54 km/hr to 1.26 km/hr and then decreased with further increase in speed to 1.62 km/hr. Also blade type and grass types both have significant effects on the weeding efficiency and effective capacity of the machine, with spear grass and horizontal blade-type having the highest significant effects. The developed machine is efficient, reduces stress, drudgery and increased area of covered per unit time. The total cost of construction of the machine was $137.

Keywords: *Blades, capacity, design, efficiency, weeding*

INTRODUCTION

Weeds are unwanted plants that are found competing with our crops for space, nutrients and serves as habitat for pest and diseases which attack and kill our crops at the long or short run before the harvest season. Weeds cause decrement in the value of land, particularly perennial weeds which tend to accumulate on long fallows; weeds growth minimizes the yield of the principal crops while untimely weeding reduces the returns from the total investments in the production of crops (Beckie 2006). Weeds account for about 50-70% reduction in yield; specifically in the humid tropics where torrential rainfall significantly interrupt work on the farms in the season. According to Oerke (2006), presently more attention is paid to insect pests (18% loss) or pathogens (16% loss) neglecting weed which accounts for about (34%) of crop losses. Egan et al. (2011) reported that adequate attention must be given to these plants (weeds) else farmers will be faced with too many losses due to the gradual havoc caused as result of weeds inversion, interference and competing with plants for space, nutrient among others.

Weiner et al. (2001) reported weeding as the process of removing unwanted plants from cultivated farmlands between the sowing stage and maturity stage (harvesting time). Weeding operation has many strategies that are generally classified into pre-emergence and post-emergence (Olsen et al. 2004). The pre-emergence include false or stale seedbed and flaming methods. While the post-emergence weeding method also known as selective weeding includes; spraying, flaming, inter-row weeding, intra-row weeding, hand and mechanical weeding (Rasmussen 2003).

According to Kumar et al. (2017), the mechanical method of weed control is the best method of weeding with little or no limitation because of its effectiveness. Though, the mechanical weeding machines are not common. Therefore, to complete weeding operation within the available period, farmers are left with the only option of manual weeding which is labour intensive and time taking. As the tractor operated weeders are not much available, are costly and are recommended for large farmland. Hence, there is a need to develop a small weeding machine for small and large scale fields. Therefore this work aims to design, fabricate and carry out performance testings of a horizontal weeding machine.

Material and Methods

Design Consideration

For an effective and maximum efficiency of the machine the following criteria and factors were carefully and critically considered to arrive at a workable and cost-effective design; weight, shape, size of the machine; mechanical property of the soil e.g. hardness, toughness, strength, moisture content, ergonomic consideration such height of the machine, material availability, affordability of materials, cost of maintenance, replaceable parts

Description of the Machine Components

Frames

The frame provides rigidity and support for the equipment. It also carries the frame support and the pulley system which makes the equipment stand without the operator holding it. It also provides a seat or compartment for the petrol engine and helps the operator to operate the implement with ease and comfort. It is shown in Plate 1 and Figure 1.

The Pulleys

This mechanism transmits power from the petrol engine using a belt to the weeding blade. The mild steel pulleys were used because of their good friction and wear characteristics and their low cost. The diameter of the driving pulley was 30 mm while that of the driven pulley was 80 mm. It is shown in Plate 1 and Figure 1.

The Belt

V-belt was used for this construction because of its suitability for short drives. Bearings: These were used to hold the shafts to the frames and allow relative motion of the shafts. The bearing of 205 was used as shown in Plate 1 and Figure 1.

The Petrol Engine

This is the source of mechanical power for the mechanism. It converts the chemical power of the petrol (fuel) to mechanical energy which in turn drives or propels the weeding mechanism ie the blades for weeding to take place. The petrol engine used was rated 6 horsepower.

Depth Adjuster

This mechanism helps to regulate or control the depth of penetration of the weeding blade to the soil during operation. It also helps set the machine to perform the mowing operation or weeding operation on the field.

Weeding Blades

This part performs the main function of the machine, which is weeding and mowing of unwanted crop plants on the farm. Two types of weeding blades used were finger and horizontal blade types as shown in plates 1 and 2 respectively.

Plate1. *The finger type of weeding blade*

Plate2. *The horizontal type weeding blade*

Frame Support

This part makes the implement stands on its own without any external support. Its helps in balancing the weight of the implement and also gives the implement rigidity as well.

Protector (Blade Cover)

The protector is a rectangular shaped device also made from mild steel and located at the top of the frame. It helps to protect the operator from the spreading or splashing of cut grasses or debris due to the direction of motion of the cutting blade. It is shown in Plate 1 and Figure 1.

Wheels; two pneumatic wheels were used for the machine as shown in Plate 1 and Figure 1.

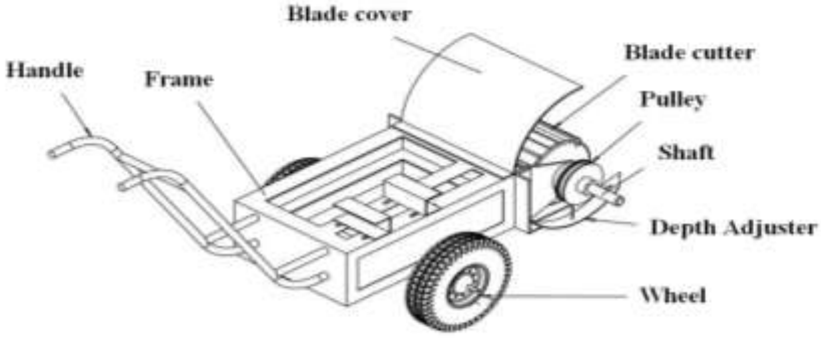

Figure1. *Isometric view of the developed machine*

Mode of Operation of the Machine

The weeding blade is fixed on the machine and the desired blade rotational speed was selected by fixing the corresponding pulley to the blade's shaft. The pulley was guided on the shafts by fixing of keyway between them. The V-belt is then mounted on both the blade and the machine pulleys. The belt tension was tested by adjusting the tight and slack sides. At a stationary position, the engine was powered with the aid of a recoil starter mechanism which in turn causes the weeding blade to rotate. The machine was pushed to the farm and the blade depth was adjusted to penetrate 35 mm into the soil. As the operator move with the required speed, this speed translates to the working speed of the machine. The power from the petrol engine was transmitted to the weeding blade, as the blade rotates the weeds are removed.

Design Calculation

The purpose of design calculations and analysis is to determine appropriate sizes and strengths of various materials used for the construction of the machine parts. Some of the major design calculation carried out includes;

Determination of the Machine Working Width

The working width is a function of the machine capacity over the machine speed and it was calculated as reported by Gbabo et al. (2019), is given as.

$$C_m = W \times V \quad (1)$$

$$W = \frac{C_m}{V} \quad (2)$$

Where: C_m is machine capacity, W is working width (m), V is working speed (m/s)

Determination of Length of the Belt

The length of the belt was calculated as reported by Khurmi and Gupta (2005), is given as

$$L_b = \frac{\pi}{2}(d_{p1} + d_{p2}) + 2C + \frac{(d_{p1} - d_{p2})^2}{4x} \quad (3)$$

Where: L_b is the length of the belt (m), d_{p1} is the diameter of the driving pulley (m), d_{p2} is the diameter of the driven pulley (m), C = center distance between the two pulleys (m),

Determination of Velocity of Belt

To determine the speed of the belt with time, it can be determined by using the following expression below reported by Khurmi and Gupta (2005)

$$V_b = \frac{\pi d_{1N_1}}{60} \quad (4)$$

Where: V_b is the velocity ratio of the belt drive (m/s), d_{p1} is the diameter of the driving pulley (m), N_1 is the speed of the driving pulley (rpm)

Determination of Angle of Contact between Belt and Pulley

The angle of contact between the belt and the two pulleys was determined to know the tension built up between the belt and the pulleys. It can be calculated by the expression below, reported by Khurmi and Gupta (2005)

$$\theta = (180° - 2\alpha) \times \frac{\pi}{180} \quad (5)$$

And, $$\alpha = \sin^{-1}\frac{(r_1 - r_2)}{x} \quad (6)$$

Where: θ is the angle of contact between the belt and pulley, r_1 is the radius of the driving pulley (m), r_2 is the radius of the driven pulley (m), x is the centre distance between the two pulleys (m)

Determination of the Belt Tension

The tension developed in the belt was evaluated to know the power transmitted by the petrol engine. It can be calculated by the expression below, reported by Khurmi and Gupta (2005)

$$K = 2.3\log\frac{T_1}{T_2} = \mu \times \theta \times cosec\beta \quad (7)$$

Where T_1 is the tension in the tight side of the belt (N), T_2 is the tension in the slack side of the belt (N), β is the average groove angle of the shaft pulley, Θ is the angle of constant or lap between the two pulleys, μ is the coefficient of friction between the belt and the pulleys

Determination of Power Transmitted by the Belt

This is done to know the amount of energy transmitted from the petrol engine pulley to the machine pulley. Power transmitted by the belt was determined as reported by Khurmi and Gupta (2005) and is given as

$$P = (T_1 - T_2) \times V \quad (8)$$

Where: P is the power transmitted by the belt (watts), T_1 is the tension in the tight side of the belt (N), T_2 is the tension in the slack side of the belt (N), V is the velocity of the belt in (m/s).

Determination of Shaft Diameter

The diameter of the central shaft was computed using the equation reported by Gana et al. (2017)

$$d^3 = 16/\pi S_s \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (9)$$

Where d is the diameter of the shaft (m), M_t is the belt torque moment (Nm), M_b is the bending moment (Nm), K_b is the shock and fatigue factor applied to bending moment, K_t is the shock and fatigue applied to torsional moment, S_S is the permissible shear stress of the shaft

Determination of Maximum Working Stress of the Shafts

This is done to know the strength of the shaft and its behavior under working conditions. It is determined as reported by Khurmi and Gupta (2005)

$$\sigma = \frac{16Ts}{\pi d^3} \quad (10)$$

Where σ is the maximum permissible working stress, d is is the shaft diameter (m), Ts is the torque of the shaft (Nm)

Testing Methods

The moisture content of the farmland was set at 16% M.C and in all the testing the depth of operation of the weeder was set at 35 mm.

Testing of the Machine

The performance of the weeding machine was evaluated. A hectare of farm field of the Department of Agricultural and Bioresources of the Federal University of Technology Minna, Nigeria was used for the study. Half of the hectares covered by spear and nut grasses each were selected. The soil moisture content of the fields was set at 16% M.C. Three sets of experiments were carried out to investigate the machine performance using two blade types horizontal and finger blade types. In the first test effects of rotational speed of the blades on the weeding efficiency of the machine were determined. The blade rotational speeds used were 1000, 1500, 2000 and 2500 rpm. In the second test interaction between the operator's speed and blade type on weeding efficiency and the machine capacity, were investigated. The operator’s speeds used were 0.54, 0.9, 1.26 and 1.62 km/hr. Each of the experiments was replicated three times using equations 11 and 13 and the results obtained are presented in Tables 1 and 2.

Performance Parameters of the Machine

The performance parameters of the machine were evaluated as follows.

- Weeding Efficiency: This is the effectiveness with which the weeding machine carries out the weeding operation and can also be defined as the percentage reduction in weed by the machine. It was determined as reported by Awulu *et al.* (2018) and is given as

  $$Wef = \frac{Wt - Wr}{Wt} \times 100 \quad (11)$$

  Where: Wef is the weeding efficiency (%), Wt is the total weight of the weeds in the plot (kg), Wr is the weight of the weed removed (kg)
- Weeding Capacity: Weeding capacity is defined as the area of land that can be cleared per day. It was calculated to determine the area of land that can be cleared per day at various speeds. It was determined as reported by Awulu *et al.* (2018) and is given as.

  $$C_{Ef} = C_{Th} \times E_{eff} \quad (12)$$

  $$C_{Ef} = \frac{W \times V}{10} \times E_{eff} \quad (13)$$

Where: C_{Ef} is the effective capacity (Ha/hr), C_{Th} is the theoretical capacity (Ha/hr), W is the machine width (m), V is the machine walking speed (Km/hr), E_{eff} is the efficiency of the machine (%)

Results And Discussion

Results

The machine was designed, fabricated and the results of the performance testing are presented in Tables 1 and 2. Table 1 represents the results of the effects of the rotational speed of the blades on weeding efficiency of the machine. The highest weeding efficiency of 95.2% was obtained from a combination of blade speed of 2500 and horizontal blade type on spear grass whereas low weeding efficiency of 60.2 % was obtained from the combination of blade speed of 1000 and finger blade type on nutgrass. The result of interaction between the operator's speed and blade type on weeding efficiency and the machine capacity was presented in Table 2. The highest weeding efficiency of 97.6 % was obtained from the interaction between operator's speeds 0.54 km/hr and horizontal blade type on spear grass whereas low weeding efficiency of 38.5 % was obtained from a combination of operator's speed of 1.62 km/hr and finger blade type on nut grass. Also, the highest machine capacity of 0.0529 Ha/hr was obtained from the interaction between operator's speeds 1.26 km/hr and horizontal blade type on spear grass whereas low machine capacity of 0.01656 Ha/hr was obtained from a combination of operator's speed of 0.54 km/hr and finger blade type on nut grass.

Table1: *Effects of the rotational speed of the blades on weeding efficiency of the machine*

S/N	Type of Grass	Type of Blade		Weeding Efficiency (%)			
			Speed of the blade (Km/hr)	1000	1500	2000	2500
1	Spear Grass	Finger Type		70.3	80.3	90.1	91.7
		Horizontal Type		75.8	82.7	94.6	95.2
2	Nut Grass	Finger Type		60.2	65.4	80.3	81.6
		Horizontal Type		65.5	68	85.9	87.2

Table2: *Effects of the operator's speed and blade type on weeding efficiency and the machine capacity*

S/N	Type of Grass	Type of Blade		Weeding Efficiency (%)				Effective Capacity (Ha/Hr)			
			Operator's Speed (Km/hr)	0.54	0.9	1.26	1.62	0.54	0.9	1.26	1.62
1	Spear Grass	Finger Type		82.4	88.4	89.2	48.5	0.0191	0.0342	0.0483	0.0338
		Horizontal Type		90.8	96.3	97.6	52.3	0.0211	0.0373	0.0529	0.0364
2	Nut Grass	Finger Type		67.7	70.2	71.3	38.5	0.0157	0.0271	0.0386	0.0268
		Horizontal Type		55.7	78.5	80.8	41.8	0.0176	0.0304	0.0438	0.0291

Discussion

Effects of Blade Speed and Grass Type on Weeding Efficiency

The effects of blade speed and grass type on weeding efficiency indicated that increasing the speed from 1000 rpm to 2500 rpm increased the weeding efficiency from 75.8 to 95.2 % (Figure 2). This could be due to increase in impact force, cutting and shearing actions of the blade with increased rotational speed blade. This is in agreement with the results of similar studies conducted by Jayesh (2009) where increases in the speed of cutting of materials increase the rate of cutting of the materials. A significant effect was observed with increasing the rotational speed of the blade from 1000 rpm to 2000 rpm. But almost constant weeding efficiency was obtained from the blade rotation speed of 2000 rpm (94.6 %) and 1600 rpm (95.2 %) with horizontal blade type on spear grass.

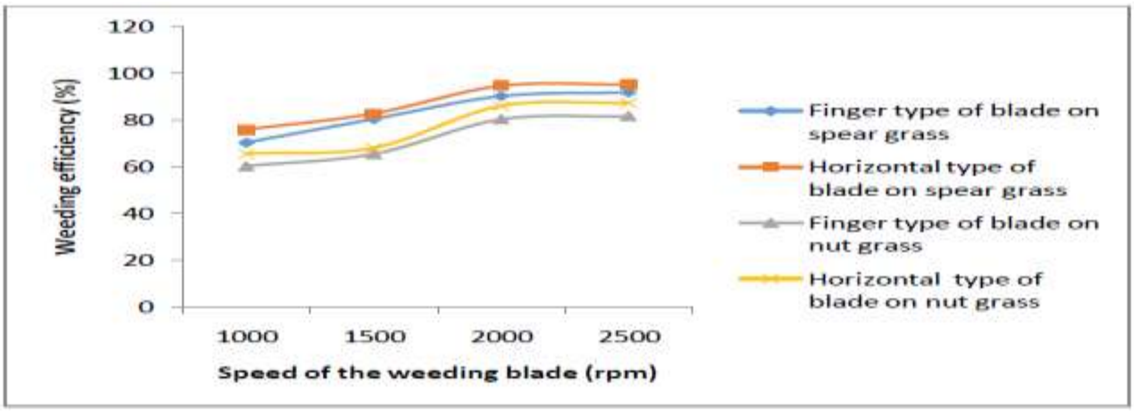

Figure2. *Results of effects of blade speed and grass type on weeding efficiency*

For the grass type, the values of weeding efficiencies were higher for the spear grass with values of 95.2% and 91.7% for horizontal and finger blade types respectively. The nutgrass recorded the lowest values of weeding efficiencies with values of 65.5% and 60.2% for horizontal and finger blade types respectively. This could as a result of more hardness and resistance of nutgrass to cutting than the spear grass.

Effects of Operator's forward Speed and Grass Type on Weeding Efficiency

The effects of operator's forward speed and grass type on weeding efficiency indicated that increasing the operator's speed from 0.54 km/hr to 1.26 km/hr increased the weeding efficiency from 90.8% to 97.6% (Figure 3) and then decreased to 52.3% with further increased in speed to 1.62 km/hr. The initial increase in weeding efficiency with increase in operator's forward speed could be as results more force associated with higher forward speed while the decreased in efficiency with further increase in speed could be a result of tiredness of the operator after few minutes of operation at a higher speed of 1.62 km/hr. This agreed with the result of an earlier study by Kumar *et al.* (2017) where weeding efficiency increased with an increase in operator's forward speed from 1 km/hr to 1.5 km/hr and then decreased with further increase in the speed to 1.8 km/hr.

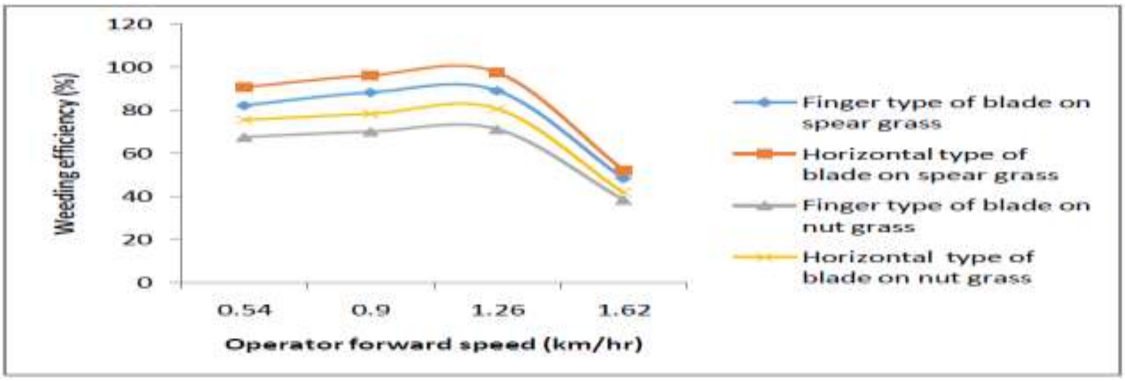

Figure3. *Results of effects of operator's forward speed and grass type on weeding efficiency*

For the grass type, the values of weeding efficiencies were higher for the spear grass with values of 97.6% and 89.2% for horizontal and finger blade types respectively. The nutgrass recorded the lowest values of weeding efficiencies with values of 80.8% and 71.32% for horizontal and finger blade types respectively. This could as a result of more hardness and resistance of nutgrass to cutting than the spear grass.

Effects of Operator's Forward Speed and Grass Type on the Effective Capacity of the Weeder

The effects of operator's forward speed and grass type on the effective capacity of the machine for all types of weeding blades indicated an initial increased in machine capacity with increasing operator's speed from 0.54 km/hr to 1.26 km/hr and drastically decreased with further increased in speed to 1.62 km/hr. The initial increase in effective capacity with increase in operator's forward speed could be as results more force associated with higher forward speed while the decreased in capacity with further increase in speed could be a result of tiredness of the operator after few minutes of operation at a higher speed of 1.62 km/hr. This agreed with the result of an earlier study by Kumar *et al.* (2017) where weeding efficiency increased with increase in operator's forward speed from 1 km/hr to 1.5 km/hr and then decreased with further increase in the speed to 1.8 km/hr, as the operator feels hard to operate the weeder and tired just after half an hour of operation.

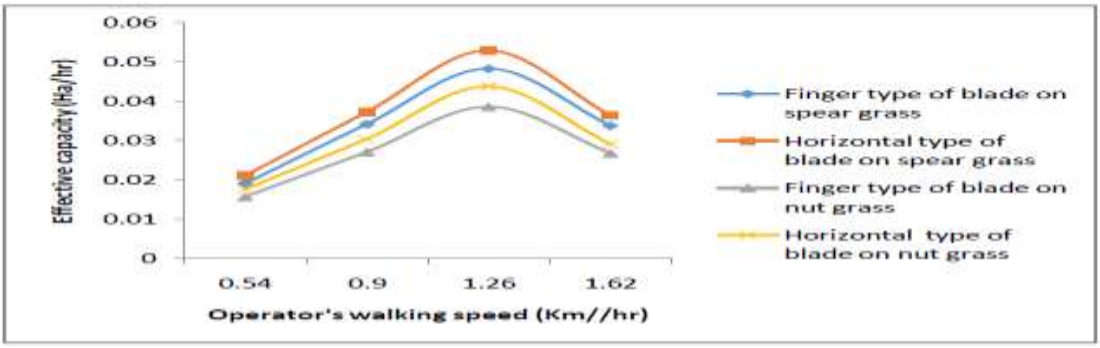

Figure4. *Effects of operator's forward speed and grass type on the effective capacity of the weeder*

For the grass type, the values of effective capacities were higher for the spear grass with values of 0.0529 ha/hr and 0.0483 ha/hr for horizontal and finger blade types respectively. The nutgrass recorded the lowest values of weeding efficiencies with values of 0.0438 ha/hr and 0.0386 ha/hr horizontal and finger blade types respectively. This could as a result of more hardness and resistance of nutgrass to cutting than the spear grass.

CONCLUSIONS

A horizontal weeding machine has been developed and tested. The total cost of construction of the machine was $137. The machine was tested at the soil moisture content level of 16 % and operation depth of 35 mm. The weeding efficiency increased with increase in blade rotational speed from 1000 rpm to 2500 rpm. Also, increasing the operator's speed from 0.54 km/hr to 1.26 km/hr increased the weeding efficiency from 90.8% to 97.6% and then decreased to 52.3% with further increased in speed to 1.62 km/hr. The effective machine capacity increased with increasing operator's speed from 0.54 km/hr to 1.26 km/hr and drastically decreased with further increased in speed to 1.62 km/hr. Besides blade type and grass types have significant effects on the weeding efficiency and effective capacity of the machine, with spear grass and horizontal blade-type having the highest significant effects. The developed machine is efficient, reduces stress, drudgery and increased area of covered per unit time.

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