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Development and Performance Evaluation of a Push-Type Mechanical Weeder

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ABSTRACT

Weeds posed a significant threat to crop yields and causing substantial losses. The traditional method of weed control is not only labor-intensive but also time-consuming. On the other hand, chemical weeds control has raised concerns due to its negative impact on the environment and human health. As the agricultural sector strives to meet consumer demands for high-quality, safe food products, there is a growing need for non-chemical weeds control solutions. Therefore, manually operated weeder was designed, fabricated, and tested in an experimental field to operate on deltaic terrain. The weeder is powered by a 1 hp petrol engine with an operating speed of 1130 rpm and equipped with 4 L-shaped standard cutting blades. The depth and width of the cut of the blades are 30 and 350 mm, respectively. During the machine test, the field location had well-drained soil classified as sandy loam with compositions of 76% sand, 7.28% silt, and 15.95% clay. The moisture content was 18%wb. Field tests conducted showed that the weeder had a field capacity of 0.016h/hr. and a weeding efficiency of 80.51%. The performance evaluation of the weeder at the tested average operating speed of 0.036m/s. The machine was designed to be simple and easy to maintain, and its overall cost of fabrication was ₦154,500, making it affordable for ordinary Nigerian farmers.

1. INTRODUCTION

Weeds are plants that grow where they are not wanted and compete with crops for resources such as space, nutrients, and sunlight. They also serve as habitats for pests and diseases that can attack and kill crops before harvest season, leading to a decrease in the value of land and crop yields (Gbabo *et al.*, 2020). It can cause 50-70% yield reduction , particularly in the humid tropics rainfall can significantly interrupt work on farms during the season (Gbabo *et al.*, 2020; Kumar, *et al.*, 2020; Sahel and Suleiman, 2021) Weed management primarily relies on three main approaches: manual, chemical, and mechanical methods. Manual weeding entails the painstaking removal of weeds using traditional tools, which, are highly effective, though can be costly, labor-intensive, and time-consuming. The labor required for this method varies based on factors such as the weed species, weed density, the timing of weeding, and the soil's moisture content during weeding activities (Woyessa, 2023; Kumar, *et al.*, 2017). In recent times, the utilisation of herbicides has been on the rise. This method is favored for its rapid and efficient weed control capabilities without causing harm to desirable plants. However, it comes with significant drawbacks, negatively impacting both human health and the environment. Herbicide use has been linked to various health concerns, including the risk of developing cancer. Additionally, it contributes to environmental problems such as air pollution, increased soil acidity, and elevated soil salinity (Gbabo *et al.*, 2020; Rangari, *et al.*, 2021). One of the most concerning aspects of herbicide application is its potential to contaminate the soil, with rainwater capable of transporting these chemicals to other areas. This contamination poses a threat to

the quality of the air we breathe, the safety of the food we consume, and the purity of the water we rely on for drinking (Manuwa, *et al*, 2009; Woyessa, 2023).

Several researchers have worked on development of mechanical weeders with different features and construction materials that are peculiar to their regions. Gbabo *et al.* (2020) developed and tested a horizontal weeding device that operates using a 6 hp petrol engine. The experiment was conducted with the machine working at a soil moisture content of 16%, and an operational depth of 35 mm. The findings indicated that the efficiency of the designed weeding machine improved as the blade rotational speed increased from 1000 rpm to 2500 rpm. In addition, as the operator's speed rose from 0.54 km/hr. to 1.26 km/hr., the weeding efficiency increased from 90.8% to 97.6%. However, further acceleration to 1.62 km/hr. led to a decline in efficiency to 52.3%. The effective machine capacity followed a similar trend, increasing with the operator's speed up to 1.26 km/hr. and decreasing beyond that point to 1.62 km/hr. The total cost of the fabricated machine was reported to be $137. Muhammad and Attanda (2012) developed a manually operated mechanical weeder, which was subsequently assessed for its performance metrics. The operational effectiveness of this weeder was then compared against that of a conventional hand-held hoe on a variety of TZPB-SR maize crop grown fields. The forward speed of developed weeder and manual hoe are 0.092 m/s and 0.013 m/s, respectively while the actual field capacity of developed weeder and manual hoe are 0.028 ha/hr. and 0.0059 ha/hr., respectively and the weeding efficiency of weeder and manual hoe are 75.17% and 77.98% respectively.

In today's agriculture, there is a growing need for non-chemical weed control methods to ensure the safety of our food supply. Consumers are becoming increasingly discerning, with a strong focus on the quality and safety of the food they consume. Addressing these concerns, the adoption of mechanical weeders is expected to have a significant impact, particularly among subsistence farmers. This technology has the potential to boost production, thereby contributing to poverty reduction (Alizadeh, 2011). Mechanical weed control stands out for its remarkable effectiveness in alleviating the labor-intensive nature of manual weeding. It not only eliminates weeds but also promotes optimal soil conditions by keeping the soil surface loose, facilitating aeration and enhancing water absorption capacity. The main hindrances to the widespread adoption of this method lie in the availability and cost of labor for weed control, underscoring the necessity of developing appropriate mechanized weeding solutions (Gbabo *et al.*, 2020)

Furthermore, the need for mechanical weeding machines has become imperative in Nigeria, driven by evolving government policies that emphasize diversifying funding sources beyond oil revenue. In response to these shifts, the development of a suitable mechanical weeder has become a pressing requirement and holds the promise of alleviating laborious manual weeding, ensuring ease of operation, and subsequently fostering increased agricultural production. To explore the feasibility of mechanizing weeding activities, an appropriate mechanical weeder was developed with careful consideration given to the optimal design, size, and proper placement of the weeding blade and performance evaluation to gauge its effectiveness for end-users. As a result, this study aimed to assess the performance of the developed weeding machine, focusing on criteria such as weeding efficiency and effective field capacity.

2. METHODOLOGY

2.1. *Materials selection*

The design utilized cost-effective materials readily accessible. All the necessary materials for constructing the mechanical weeder were obtained from local markets. The majority of the weeder's components were fabricated within the workshop of the Food and Agricultural Engineering Department, Kwara State University, Malete.

2.2. *Design considerations*

The following factors were considered in the development of the mechanical weeder.

i. The density and the condition of weed
ii. Soil physical characteristics (soil moisture content, bulk density)
iii. The characteristics of the interface between soil and the soil acting elements of the weeder
iv. Soil-implement interface (width of cut, depth of cut, soil cohesion)..
v. Distance between rows to row.
vi. Minimum force needed for field operation.
vii. Adjustment made simple and easy.
viii. Utilize locally available materials to minimize fabrication costs.
ix. Lightweight for convenient handling.
x. Simple to repair and maintain.
xi. Suitable for operation by a single individual.

2.3. *Machine Description and Working Principle*

The mechanical weeder consists of prime mover (petrol engine), four set of rectangular blades in each side arranged in circular pattern, transmission gears, clutch cable, throttle cable, handles, blade guard, two pneumatic tyres and protective rubber for handles. Working principle of the machine after starting the engine, the clutch is engaged, and the blades is set into motion. The blades do not only remove the weed from the farm but also provide traction for the machine during field

operation. However, the two pneumatic tyres are provided for the machine to ease the movement from one point to another, to provide stability for the machine and also to control the level of cutting by moving the machine front and backward. The higher the throttle the more the speed of the blades. The handles are used to control the direction of the machine. After the operation the throttle is released, clutch is disengaged, and machine was put off. Figures 1 and 2 shows the isometric view and exploded views, respectively of the designed mechanical weeder.



Figure. 1: Designed model of Mechanical Weeder.

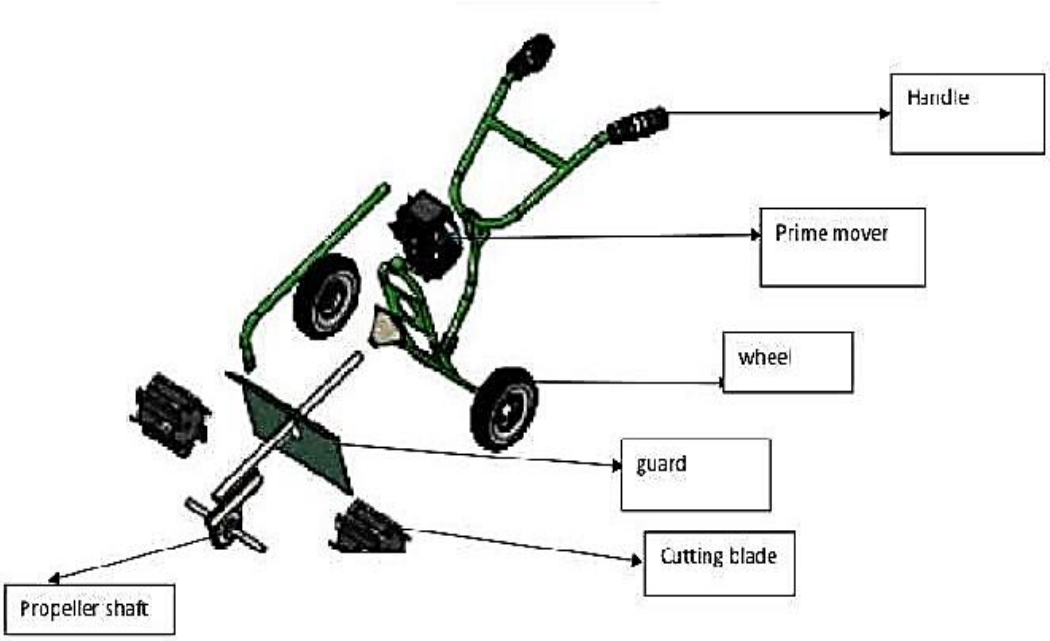


Figure. 2: Exploded View of the Designed Mechanical Weeder.

2.4 Design Calculation

The primary aim of engaging in design calculations and analysis is to ascertain the suitable sizes and strengths of the materials employed in fabricating machine parts. Several key design calculations are conducted as follows.

2.4.1 Determination of the Machine Working Width

The operational width is defined as the ratio of the machine's capacity to its developed speed, as reported by Gbabo *et al*. (2020) and expressed in equation (1).

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

$$W = \frac{C_m}{V}$$

where,
C_m = Capacity of the machine,
W = Width of the machine (m),
V = Working speed (m/s)

2.4.2 Weeder Draft

The draft of the weeder can be calculated as using the relationship in equation (2) as reported by (Muhammad, 2016).

$$D = W \times d_w \times R_s \quad (2)$$

where,
D = Weeder draft, (N),
W = Width of cut (cm),
d_w = Depth of cut (cm),
Rs = Soil resistance (Kg/cm^2).

2.4.3 Power Requirement

Power required to push the designed weeder can be calculated from relationship stated in equation (3) as reported by (Muhammad, 2016).

$$Power = \frac{Draft\ force\ (N) \times Machine\ speed(m/s)}{1000} \quad (3)$$

2.4.4 Soil Resistance (R_S)

This is the average soil resistance to the design implement, given by the relationship reported in equation (4) (Muhammad, 2016)

$$R_s = \frac{Weeder\ Weight}{Total\ Area\ of\ Weeder\ in\ Contact\ with\ the\ soil} \quad (4)$$

$$R_s = \frac{Weeder\ Weight}{(2 \times L \times B) + (L_f \times B_f)}\ kg/Cm^2$$

Where:
L = Weeder blade length (cm)
B = Weeder blade thickness (cm)
L_f = length of weeder float (cm)
B_f = breadth of float (cm)

2.5 Performance Evaluation of the Weeder

The field experiment of mechanical weeder was evaluated under different field conditions, before the weeding operations, the following parameters were noted.

2.5.1 Crop parameters

Plant height: Measured by randomly selecting plants in the field and measuring their height.

Field parameters:

Type of soil: Determined by taking random soil samples from different places within the experimental field.

Moisture content is assessed by analyzing soil samples through the standard oven-dry method. Bulk density is measured using a bulk density sampler, while the length and width of the field are directly measured using a standard measuring tape. In order to evaluate the field performance of the weeder, the following parameters were computed:

i. Operation time
ii. Weeding efficiency
iii. field capacity

iv. Field efficiency

2.5.2 Operational Parameters

a) Moisture Content of the Soil

To determine the moisture content of the soil, the following were steps follow:

i. Five random samples were collected from the field,
ii. each sample were weighed and record,
iii. samples were placed in an oven set to 105 ºC for 24 hours to dry,
iv. After 24 hours, remove the samples from the oven and weigh and new weights were recorded,
v. The Calculate the moisture content was calculate using the relationship equation (5) as reported by (Woyessa (2023).

$$M(dry\ basis) = \frac{W_W - W_d}{W_d \times 100} \quad (5)$$

where,
M = Moisture content of soil, %
Ww = Weight of wet soil, gm and
Wd = Weight of oven-dry soil, gm

b) Bulk Density of Soil

The soil's bulk density serves as a crucial parameter, indicating the level of compaction within the soil and is defined as the mass per unit volume. The determination of soil bulk density involves the following steps:

i. Collection of soil samples from experimental plots using a core sampler. The core sampler is driven vertically into the ground, ensuring it is deep enough to fill the sampler (0 to 15 cm).
ii. Measurement of the weight of each soil sample, followed by placement in an oven set at a constant temperature of 105 °C. The samples are retained in the oven until a constant weight is achieved.
iii. The weight of the oven-dried samples was recorded.

The bulk density was calculated using the following equation (6) as reported by Woyessa (2023).

$$\rho_b = {}^{M}/_{V} \quad (6)$$

where,
ρ_b = bulk density of soil, g/cm^3
M = oven dry mass of soil, g and
V = volume of core sampler, cm^3

2.5.3 Machine Performance Parameters

The evaluation of the mechanical weeder's performance such as weeding efficiency and field capacity were determined for the machine evaluation as follows.

a) Theoretical Field Capacity

The field capacity depends on both the speed of the implement and its designated width. It signifies the rate at which the implement should ideally cover the entire field if it were to function continuously at its rated speed, consistently covering the full width it's designed for. This theoretical field capacity can be computed for the relationship in equation (7) as reported by (Muhammad and Attanda, 2012)

$$TFC = \frac{W \times S}{10} \quad (7)$$

where,
TFC = Theoretical Field capacity, ha/h
S = Speed of operation, km/hr and
W = Width of implement, m

b) Effective Field Capacity

To determine the effective field capacity, the time spent on productive work as well as the time allocated for various ancillary tasks, including turning, cleaning, machine adjustments, and troubleshooting. Precise measurements of the plot's dimensions were taken, and the area covered within the specified time was computed. By determining the area covered per hour, the actual field capacity, representing the genuine average rate of coverage by the implement, was calculated. The overall time needed to complete the operation was recorded, and the effective field capacity was then computed according to the method reported by Muhammad and Attanda (2012), as expressed in equation (8).

$$EFC = A(T_p + T_l) \quad (8)$$

Where:
EFC = Effective field capacity, ha/hr
A = Actual area covered, ha and

T_p = Productive time, hr
T_i =Non-productive time, hr

c) Weeding Efficiency

Weeding efficiency is defined as the proportion of weeds eradicated by a weeder in relation to the initial number of weeds within a defined unit area, typically expressed as a percentage. To measure this, a square metallic frame measuring 1 m^2 was placed randomly within the test field. The number of weeds within the frame was counted both before and after the weeding process. Each treatment was replicated three times, and observations were recorded for each replication. The calculation of weeding efficiency was performed using the relationship in equation (9) as reported by (Owolarafe et al. (2013).

$$Weeding\ efficiency\ (\%) = \frac{W_1 - W_2}{W_1 - 100} \qquad (9)$$

Where:
W_1 = Number of weeds counted per unit area before weeding operation
W_2 = Number of weeds counted in the same unit area after the weeding operation

2.4. *Experimental Field*

Machine testing, the field location had well-drained soil classified as sandy loam with compositions of 76% sand, 7.28% silt, and 15.95% clay and the moisture content was 18%wb. The performance indicator of the push- type engine-operated weeding machine was expressed in terms of weeding efficiency, field capacity, and the costs of designed and fabrication of the machine were calculated. Three plots were selected, each measuring 12.5 m × 12.5 m.

3. RESULTS AND DISCUSSION

3.1. *Field capacity*

The weeder was operated within these plots, and various observations were recorded, with the details provided in Table 1. The calculated field capacity for the developed weeder was approximately 0.016 ha/h. In contrast, Muhammad and Attanda (2012) reported a field capacity of 0.028 ha/h, while Muhammad (2016) documented a higher value of 0.357 ha/h. It is essential to note that the field capacity is directly influenced by factors such as the cutting width and the physical and mental conditions of the operator. A reduction in the effective cutting width can lead to a corresponding decrease in field capacity.

Table 1: Field capacity of mechanical weeder

Plot	Area of plot (ha)	Time taken (hours)	Field capacity	Average capacity
1	0.0156	0.917	0.0163	
2	0.0156	1.003	0.0156	0.016h/hr
3	0.0156	0.967	0.0161	

3.2. *Weeding efficiency*

The assessment of weeding efficiency was carried out on three designated plots of land situated in different locations. The outcomes of the experiment were documented and presented in Table 2. The calculated average weeding efficiency was determined to be 80.51%. This finding aligns with a study conducted by Muhammad (2016), wherein optimal weeding efficiency of 84.5% was observed at a soil moisture content of 40.8%, contrasting with a weeding efficiency of 53.1% at 10.5% soil moisture content. In addition, a similar trend was identified in the research carried out by Muhammad and Attanda (2012), where a weeding efficiency of 75.17% was achieved. It's noteworthy that weeding efficiency varies across different test zones or field locations, influenced by factors such as the root zone depth of weeds, the blade's shape, the moisture content of the soil at the testing site, and the cutting depth of the weeder blades.

Table 2: Field efficiency of the mechanical weeder

S/N	Experimental Area 12.5 m × 12.5 m	Weeded Area (m^2)	Unweeded Area (m^2)	Weeding Efficiency (%)	Average Efficiency (%)
1.	A	140.4	15.85	89.86	
2.	B	127.0	29.25	81.28	80.51
3.	C	110.0	46.25	70.40	

3.3. *Bill of Engineering Measurement and Evaluation*

The materials used for construction of designed mechanical weeder were listed in Table 3 with their unit price.

Table 3: The bill of materials for the designed mechanical weeder.

S/N	Components	Materials specification	Quantity	Amount
1	Prime mover	1.5 hp, single cylinder	1 piece	65,000
2	Galvanized pipe	25 mm	2 lengths	12,000

3	Pneumatic wheel	9''Step AP 214	1 pair	10,000
4	Mild steel plate	3 mm, 3''x 2''	1 piece	8,000
5	Mild steel rod for wheel	25 mm	2 ft (610mm)	6,000
6	Rubber Handle	25 mm	1 pair	1,500
7	Accelerator cable	3mm x 610mm	1 piece	4,500
8	Bolts nuts and washer	M13	1 dozen	1,000
9	Bolts nuts and washer	M11	1 dozen	1,000
10	Power transmission	8mm x 1.2m	1 piece	15,500
11	Low hydrogen electrode	Gauge 10	1 pack	5,000
12	Cutting disc	10''	2 pieces	1,000
13	grinding disc	6''	1 piece	1,000
14	Filler	8mm	1 roll	1,000
15	Spring lock washer	10mm	1 dozen	3,00
16	Workmanship			20,000
17	Total			154,500

4. CONCLUSION

A hand-pushed mechanical weed control device was designed and fabricated for effortless operation. The equipment boasts a lightweight construction, ensuring ease of use with minimal exertion. Not only does it save valuable time and energy, but it also proves to be highly effective in weed removal. The machine is specifically engineered to enhance the quality of life for small-scale farmers by alleviating the strenuous task of manual weeding. The field trials conducted on this innovative weed control machine demonstrated an impressive efficiency rate of 80.51%, while causing no harm to plants. The average cost of acquiring this efficient weeding solution is N154,500.00. With its user-friendly design and cost-effectiveness, the device stands out as a promising solution for farmers seeking to improve their cultivation practices.

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