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Development and Optimization of a Hand Push Mechanical Rotary Hoe

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Abstract: *Soil cultivation is the process of breaking up the top layer of soil to improve soil preparation for a new or existing crop. Therefore, this research aimed to develop a hand push rotary hoe for soil cultivation. The machine was designed based on standard considerations for machine design and the fabrication was carried out using locally available materials. Also, the performance evaluation of the rotary hoe was conducted at the Teaching and Research Farm of the Department of Agricultural and Environmental Engineering, the Federal University of Technology Akure to determine the effects of operation parameters (Clearance and machine speed) on the performance of the rotary hoe which includes its ability to remove the weed and manipulate the soil. The result shows that the highest weeding efficiency of the rotary hoe was 90%, while the maximum weeding capacity of the rotary hoe was 126.9 m^2/h. The developed model shows that the combination of machine speed and clearance can significantly predict about 90.13% 85.05% and 90.13% change in the weeding efficiency, weeding capacity, and uncleared weed respectively. The optimal performance of the rotary hoe was 92.18%, 7.82%, and 93.23 m^2/h for weeding efficiency, uncleared weed, and weeding capacity respectively with the highest desirability of 89.3% when operated at a machine speed of 2420 rpm and 0 mm clearance.*

Keywords: *performance, rotary hoe, tilling, weeding capacity, weeding efficiency.*

1. INTRODUCTION

Cultivating is the practice of removing weeds from the garden and loosening the soil to improve air, water, and nutrient retention and penetration. Cultivation enhances soil structure and fertility while also allowing fertilizer, manure, and lime to be applied. Weed control is one of the most time-consuming and labourious agricultural tasks due to labour expenditures, time commitment, and exhaustion. Weeding by hand is inconvenient for farmers [1]. Cultivation refers to a set of equipment, materials, and techniques that, when properly combined, help to promote and maintain good soil health and tilth. This refers to the general physical properties of soil such as texture, structure, permeability, consistency, drainage, and water-holding capacity. In a nutshell, tilth is the ratio of a soil's workability to its ability to support plant growth [2]. Soil cultivation aids in the development and maintenance of good soil structure and tilth, which includes texture, structure, permeability, consistency, drainage, and water-holding capacity.

Primary tillage loosens and opens compacted or untilled soils, allowing for faster root penetration and better air/gas and water relations. Cultivation promotes soil particle aggregation by vertically dispersing organic matter e.g., cover crops, compost. Soil changes, which offer energy and nutrients to the soil organisms that form aggregates. The development of chemical bonds is aided by the restructuring of soil particles, which leads to the production of soil aggregates. Secondary tillage reduces the size of surface soil particles, resulting in a better seedbed [3].

Vegetables, cereal crops, grains, and legumes are all grown with shallow soil tillage. The amount of energy needed to make the soil beds is significant compare to deep and shallow cultivation. Deep farming on a large scale necessitates a lot more effort and time. Shallow cultivation consumes significantly less energy. The compaction and density of the soil, as well as the method used, will be decisive factors [4]. Compacted, clayey soils are much more difficult to dig up to any significant depth, and doing so on a big industrial-farm scale could be expensive [4].

The higher destructive nature of weeds compared with yields is poising main threat to crop production. The invasion rate on Nigerian soils is extremely high, especially during rainy seasons when soil moisture levels are high and plant development conditions are perfect. The highlights, prospects, performance evaluations, and limitations of weeding machines such as the ridge profile weeder, straddle-row rotary weeder, reciprocating weeder, garden row weeder, powered

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hand held weeder, rotary power weeder, row crop weeder, row-crop mechanical weeder, mechanical weeder, a multi-row power weeder, a wheeled long-handle weeder and hand-pushed mechanical weeder and so on have been reported by various researchers [5]. The weeding efficiency, field capacity, depth of cut, operating speed, and field efficiency were all evaluated as unique advantages and operational factors. Weeding efficiency, field capacity, depth of cut, operating speed, and field efficiency were all between 63.50 and 95 percent, 0.004 and 0.2 ha/hr, 0.02 and 0.4 m, 0.04 and 0.85 m/s, and 56.25 and 91.50 percent, respectively. It has been reported that the weeding efficiency, field capacity, depth of cut, and field efficiency all improved as the weeding machine's working speed increased. The automation of the weeding process has the potential to boost growth, increase harvest production, and improve the quality of farm produce. Improved weeding technique will influence item quality, handling effectiveness, least loss of homestead product, and expanded in ranch produce [5].

Different scholars have worked on rotary power weeders but this paper focused on the development and optimization of a mechanical rotary hoe system which helps to effectively lessen drudgery involved in the mini cultivation of the soil and manual weeding. It performs weeding operation and buried the weeds into the soil in diverse crop production. The throwing actions from the rotary hoe blades preserves the soil surface ripped ensuring soil aeration, improved soil structure and high-water intake capacity.

2. MATERIALS AND METHODS

The orthographic and isometric views of the developed mechanical rotary hoe are presented in Figures 1 and 2 respectively. It comprises a frame, rotary hoe (drum), flat blades, power, and transmission units.

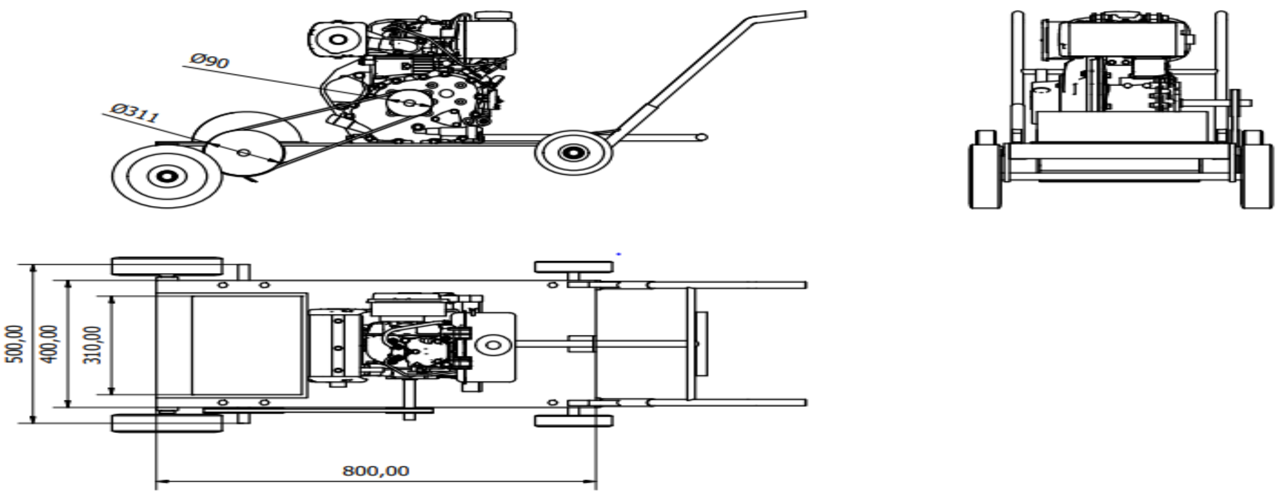

Figure 1: Orthographic View of the Mechanical Rotary Hoe

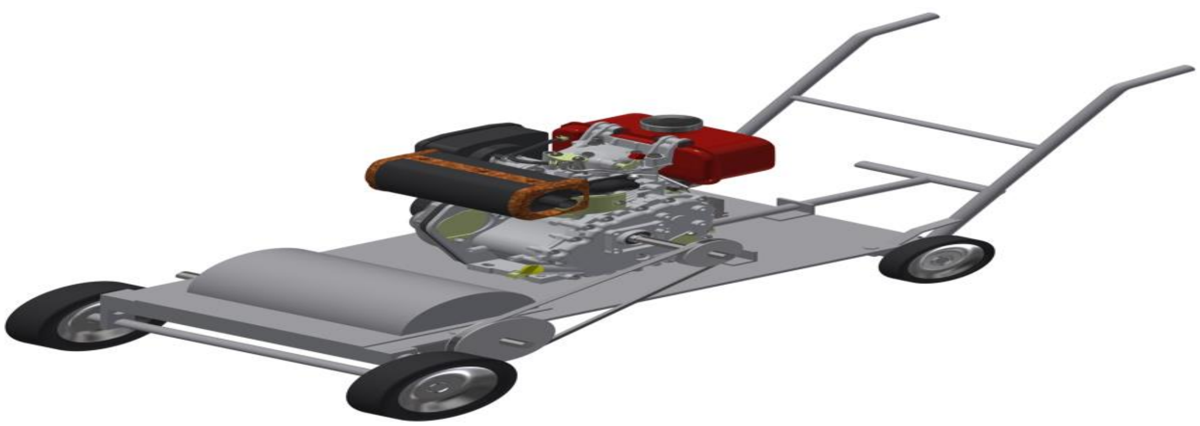

Figure 2: Isometric View of the Mechanical Rotary Hoe

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S/N	COMPONENTS
1	HANDLE
2	ENGINE
3	HOE COVER
4	BOLT
5	PILLOW BLOCK
6	WHEEL
7	WHEEL BEARING
8	SHAFT
9	MACHINE FRAME
10	BELT AND PULLEY
11	HOE

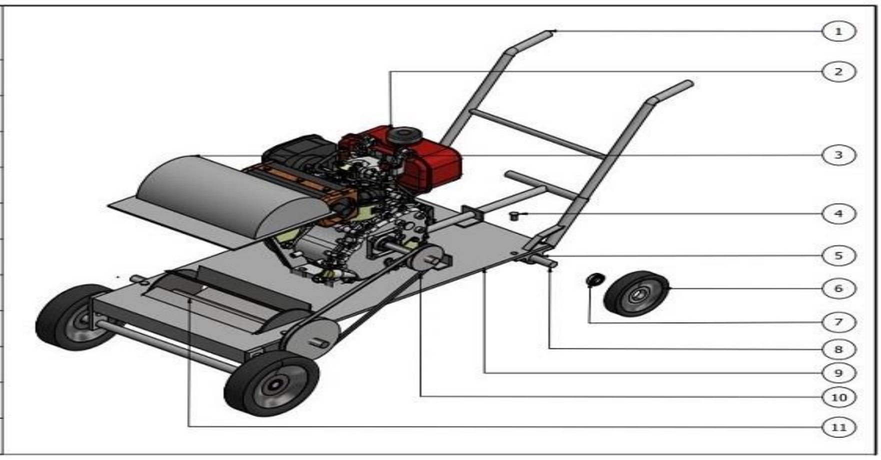

Figure 3: Parts drawing of the Mechanical Rotary Hoe.

2.1 Design Calculations

2.1.1 Weeder blade selection

The blade dimensions were 280 mm × 30 mm × 3 mm to allow the blade to penetrate deep into the soil at the weed depth to perform the weeding operation. The blade is to be attached to two plates at the sides with a shaft between them.

2.1.2 Power requirement

The draft of the weeder was determined using Equation 1 as recommended by [6].

$$Draft\ of\ the\ weeder = W\ x\ Dw\ x\ Rs \quad (1)$$

Where W is the width of cut (mm), Dw is the depth of cut (mm) and Rs is the soil resistance (Kg/cm^2)

Soil resistance for a sandy loam soil is 0.25 N/mm^2 [6], width of cut is 280 mm since the blade length is 280 mm and depth of cut is 30 mm. Substituting the width of cut, the depth of cut and the soil resistance. Therefore, draft of the weeder was 2100 N.

The total power requirement was determined using Equation 2 as recommended by [7]. The weeder is expected to operate at a speed of 1.2 Km/h to 1.95 Km/h and belt-pulley power transmission efficiency is taken to be 80 %.

$$Total\ power\ requirement\ = \frac{Draft(N) \times Speed(m/s)}{Efficiency(\%)} \quad (2)$$

Substituting the draft of the weeder = 2100 N, speed = 0.542 m/s and belt-pulley power transmission efficiency is taken to be 80 %. Therefore, total power requirement was 1422 W. Since 1 hp = 0.746 KW; total power requirement = 1.91 hp. Therefore, an engine of 3 hp was selected as the power source of the weeder.

2.1.3 Design for belt transmission

1. Design for belt and pulley

Minimum revolutions required for weeding was assumed to be 150 rpm at soil moisture content of 11.3 % (db) [8]. The diameter of the pulley was determined using Equation 3 as recommended by [7].

$$N_1D_1 = N_2D_2 \quad (3)$$

Where N_1 is the maximum selected motor speed, D_1 is the diameter of the driver pulley, N_2 is the Selected shaft speed. Substituting N_1= 2420 rpm, D_1 = 90 mm, N_2= 700 rpm. Therefore, D_2 = 311 mm.

2 Determination of belt speed

Belt speed was determined using Equation 4 as recommended by [7].

$$V = \frac{\pi D_1 N_1}{60} \quad (4)$$

Where V is the belt speed, D_1 is the diameter of the driver pulley= 90 mm and N_1 is the maximum selected motor speed = 2420 rpm. Therefore, the belt speed was determined as 11.4 m/s.

3. Determination of belt length

The belt length was calculated using Equation 5 as suggested by [7].

$$L = 2C + \frac{\pi}{2}(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \quad (5)$$

where L is the total length of the belt, C is the actual distance between the pulleys, D_2 is the diameter of the larger pulley, and D_1 is the diameter of the small pulley. Substituting the values of C = 0.311 m, D_2 = 0.311 m, and D_1 = 0.09 m. Therefore, L = 1.6 m.

4. Determination of pulley weight

The pulley weight was determined using Equations 6 and 7 as recommended by [7].

$$V_p = \frac{\pi \times D_2 \times T_P}{4} \tag{6}$$

Where, V_p is the volume of the pulley, D_2 is the diameter of the larger pulley, T_p is the thickness of pulley. Substituting the values of D_2 = 0.311 m, and T_p= 0.04 m. Therefore, V_p = 0.003 m^3.

$$W_p = V_p \times \rho \times g \tag{7}$$

Where, W_p is the weight of the pulley, V_p is the volume of the pulley, ρ is the density of mild steel, and g is the acceleration due to gravity. Substituting the values of V_p = 0.003 m^3, ρ = 7850 Kg/m^3, and g = 9.8m/s^2. Therefore, W_p= 234 N.

5. Wrap angle

The wrap angles were calculated using Equations 8, 9 and 10 as suggested by [7].

$$\Theta_1 = 180 - 2\beta \tag{8}$$

$$\Theta_2 = 180 - 2\beta \tag{9}$$

$$\text{Sin } \beta = \frac{R-r}{C} \tag{10}$$

Where, R = 0.156, r = 0.045, C = 0.34. Substituting the values, β = 19˚, Θ_1 = 142º = 2.48 rad for driven pulley, Θ_2 = 218º = 3.80 rad for driving pulley.

6. Tension acting on the driven pulley

Tension acting on the driven pulley was determined using Equations 11, 12 and 13 as recommended by [7].

$$\frac{T_1}{T_2} = e^{\mu\theta} \tag{11}$$

$$T_1 = 4.132T_2 \tag{12}$$

$$P = (T_1 - T_2)\ V \tag{13}$$

Where P is the power requirement = 1422 W, and V is the velocity = 11.4 m/s, Where, T_1 is the tension in the tight side, T_2 is the tension in slack side, μ is the co-efficient of friction between leather belt and metal pulley, T_1 = 164.55 N, T_2 = 39.823 N, μ = 0.4, Θ_2 = 218º = 3.80 rad.

7. Determination of torsional moment

The torsional moment was determined using Equation 14 as recommended by [9].

$$M_t = \frac{D_2(T_1 - T_2)}{2} \tag{14}$$

Where M_t is the torsional moment, T_1 is the tension in the tight side, T_2 is the tension in slack side and D is the diameter of the driven pulley. Substituting the values of D = 0.311 m, T_1 = 164.55 N and T_2 = 39.823 N. Therefore, M_t =19.40 N

8. Design of shaft

The weight of blades, the weight of the plates and shaft diameter were determined using Equations 15 to 17 as recommended by (7). Shaft length = 500 mm

Cutting blades and plate is made with mild steel of density 7850 Kg/m^3

$$W = V\rho Nb \tag{15}$$

Where W is the weight of blades, V is the volume, ρ is the density, Nb is the number of blades

$$W = 0.28\ x\ 0.003\ x\ 0.03\ x\ 7850\ x\ 6 = 1.19$$

$$Wp = 2v\rho \tag{16}$$

Where Wp is the weight of plates, v is the volume, ρ is the density.

$$Wp = 2 \times \pi \times 0.08^2 \times 0.003 \times 7850 = 0.97$$

$$Total\ weight\ of\ blades\ and\ plates = 1.19 + 0.95 = 2.13\ N$$

Converting uniformly distributed load of the blades and plate to point load:

$$Point\ load\ of\ blades\ and\ plates = 2.13\ x\ 0.28 = 0.60\ N$$

Pulley weight = 234 N

M_b = 11.7 Nm

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$$d^3 = \frac{16}{\pi Ss}\sqrt{(M_t K_t)^2 + (M_b K_b)^2} \quad (17)$$

where d is the shaft diameter, Ss is the allowable Shear Stress = 40 MN/m^2 since the shaft is with keyway, M_t is the torsional moment = 19.395 N, M_b is the bending moment = 11.7 Nm, K_b = 1.5 and K_t = 1 since it is a gradually applied load and a rotating shaft. Substituting the values to equation 17. Therefore, the diameter is 15 mm. A shaft of 20 mm diameter was selected for the machine construction.

2.2 Description of the Major components of the Mechanical Rotary Hoe

The major components of the mechanical rotary hoe include the frame, the wheel, the transmission system, the rotary hoe (drum and blades), and the guard plate. Table 1 shows the hhighlights of the suitable materials, the selected and justification for selection.

The Frame: The frame forms the platform on which other components are fixed. The consideration mainframe material selection was based on the adequate weight with the requisite strength and reliability, as well as being easily available. Mild steel angle iron with a thickness of 30.20 mm by 30.20 mm by 3 mm was used. The angle iron selected was considered less heavy than other materials while still having required strength properties. The length of the mainframe used in this design is 870 mm.

The Wheels: The rotary hoe has four wheels. Two each at the front and the back, the front wheels serve as stability and the two at the rear have a steering capacity which makes it easier to maneuver during operation.

Transmission system: Power was delivered to the rotary hoe blades through a belt and pulley system. A 3-hp gasoline engine powered the machine. By welding a small diameter sprocket to the crankshaft, the belt and pulley can be replaced with a chain and sprocket.

The Rotary Hoe (Drum and Blades): This is made of mild steel and measures 280mm x 30mm in size. Welding is used to join the blade to a perforated drum. It has the appearance of a flat blade. The output shaft drives the cutting blades through a belt drive. The cutting was done one blade at a time, one after the other. Naturally, this lowers the amount of power required to cut through the soil. The blades could attain maximum cutting depth, allowing them to cut and bury weeds while also limiting regrowth.

The guard plate: This is a shield that protects the blades of the gang. The shield keeps cut weeds and soil out of the way of the operator and engine.

Table 1: Highlights of the Suitable Materials, the Selected and Justification for Selection

S/N	Name of components	Suitable materials	Selected materials	The justification for the selected material
1	Shaft	Medium carbon, galvanized steel	Medium carbon steel	The cost, high machinability and availability
2	Prime mover	Diesel engine, petrol engine, electric motor.	Petrol engine	Availability, cost, weight on the frame and power required.
3	Pulley	High carbon steel, cast iron, mild steel	Mild steel	The strength to withstand the stress of high speed
4	Belt	Leather, rubber	Rubber	Easy operation and safety of the operator.
5	Handle	Galvanized steel, High carbon, mild steel.	Galvanized steel	Machinability and lightweight.
6	Frame	High carbon steel, mild steel	Mild steel	Ruggedness and prevent rust.
7	Bearing	Pillow bearing, ball bearing, bush bearing	Ball-bearing	Ease of operation and aid easy transmission of motion.
8	Drum	Mild steel, high carbon steel	Mild steel	Prevent rusting, machinability.
9	Disc	Mild steel, high carbon steel	High carbon steel	Availability and ruggedness
10	Wheel	Steel track, rubber, metal	Rubber	Availability, balancing, good support.

2.3 The Description of Experimental Site, Evaluation Material and Procedure

The machine was evaluated based on the weeding efficiency, the weeding capacity, and the effect of machine speed and clearance on the uncleared weed. The performance evaluation of the mechanical rotary hoe was conducted at the Teaching and Research Farm of the Department of Agricultural and Environmental Engineering, Federal University of Technology Akure. The performance evaluations were conducted to determine the effects of operation parameters on the performance of the rotary hoe which include its ability to remove the weed and manipulate the soil. Weeds including Tridax procumbex, Sida acuta, and Eleusine indicae dominated the experimental area. The evaluation was performed using 3x4 in split spit block design, where 4 levels of Clearance and 3 levels of Machine speed were considered as the experimental variables and the total of 12 experimental runs (Table 2). The selection of the Clearance levels (0 mm, 2 mm,

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4 mm, 6 mm) was done based on the values reported by [10], for the evaluation of a rotary power weeder and the machine was evaluated at 0 mm clearance to understand it ability to till the soil as a mechanical hoe. Also, the selection of the machine speed levels (1660 rpm, 2080 rpm and 2420 rpm) was considered based on the design power and capacity of the prime mover; and the actual speed was measured using tachometer before operation.

Table 2: Experimental Design of the Machine

Clearance	0	2	4	6	0	2	4	6	0	2	4	6
Speed	2420	2420	2420	2420	2080	2080	2080	2080	1660	1660	1660	1660

2.4 The Performance Evaluation Parameters of the Mechanical Rotary Hoe

The performance evaluation parameters were determined using equations 18 to 22.

2.4.1 Weeding efficiency

Weeding efficiency is the ratio of the area of weed cleared to the theoretical capacity of the mechanical weeder and it was expressed as a percentage in equation 18 [11].

$$WE = \frac{W_2}{W_1} \times 100 \tag{18}$$

Where WE is the weeding efficiency in %, W_1 is the marked-out area before weeding in m^2, and W_2 is the weeded area after weeding operation in m^2.

2.4.2 Weeding capacity

Weeding capacity is the ratio of the area of weed cleared to the time taken to complete the operation and it was expressed as a percentage in equation 19 by [11].

$$WC = \frac{W_2}{t} \tag{19}$$

Where WC is the weeding capacity in m^2/h, W_2 is the weeded area after the weeding operation in m^2 and t is the time taken to complete the operation hour (h).

2.4.3 Uncleared weed

The uncleared weed (UCW) was determined using equation 20 as reported by [12].

$$UCW = 1 - \frac{W_2}{W_1} \times 100 \tag{20}$$

Where UCW is the uncleared weed in % , W_1 is the marked out area before weeding in m^2 and W_2 is the weeded area after weeding operation in m^2.

2.4.4 Tilling efficiency

Tilling efficiency was determined as the ratio of the tilled area to the theoretical tilling capacity of the mechanical rotary hoe and it was expressed as a percentage in equation 21 by [10].

$$TE = \frac{T_2}{T_1} \times 100 \tag{21}$$

Where TE is the tilling efficiency in %, T_1 is the marked-out area before the operation in m^2 and T_2 is the tilled area after the operation in m^2.

2.4.5 Tilling capacity

Tilling capacity was determined as the ratio of the tilled area to the time taken to complete the operation and it was expressed as a percentage in equation 22 by [10].

$$TC = \frac{T_2}{t} \tag{22}$$

Where TC is the tilling capacity in m^2/h, T_2 the tilled area is after the operation in m^2 and t is the time taking to complete the operation in h.

2.5 Statistical Analysis

By using the central composite design method for the Analysis of Variance (ANOVA) and optimizing responses within the limit of the independent factors tested, the Response Surface Methodology (RSM) of the Design Expert Version 11 was used for the optimization process. The evaluation was performed at four different clearances (0 mm, 2 mm, 4 mm, 6 mm) and three machine speeds (1660 rpm, 2080 rpm, and 2420 rpm).

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3. RESULTS AND DISCUSSION

Figures 4-8 present the weeding efficiency, weeding capacity, uncleared weed, tilling efficiency and tilling capacity.

3.1 Weeding Efficiency (%)

Figure 4 reveals the weeding efficiency of the developed machine. According to the figure, the weeding efficiency ranges from 52% - 89%. The maximum value (89%) of the weeding efficiency was recorded at machine speed and clearance of 2420 rpm and 0 mm respectively, meanwhile, the minimum value (52%) of the weeding efficiency was recorded at machine speed and clearance of respectively 1660 rpm and 6 mm. The obtained value in this study is similar to the result (72.29 – 99.18%) reported by [13] – [23], which ranged from 63.50 – 95 % for manually operated rotary weeder for a dry land crop [24] also reported a similar weeding efficiency of 82-90% for a different type of weeder (push-type, hand khurpi, power weeder, and cycle weeder), also, the result of this study was higher than the value (54.98% to 59.05%) at a cutting speed of 1804 rpm to 2261 rpm reported [25] during the design, fabrication and evaluation of a rotary power weeder. The mathematical relationship between the weeding efficiency and the input parameter (clearance and machine speed) is shown in Equation 23 with a determination coefficient of 0.9013 and this shows that the equation can significantly ($P<0.05$) predict the 90.13% change in the Weeding efficiency as a function of machine speed and clearance.

$$WE = 47.43 - 4.47C + 0.02S \quad (23)$$

where WE is the weeding efficiency, C is the clearance (mm) and S is the machine speed (rpm).

Table 3 reveals the result of the analysis of variance (ANOVA) of the weeding efficiency. Based on Table 2, the combination of machine speed and clearance can significantly explain the variation in the weeding efficiency at a 100% probability level and a similar observation was reported by [25]. However, the change in the weeding efficiency significantly ($P<0.05$) depends on the clearance followed by the machine speed

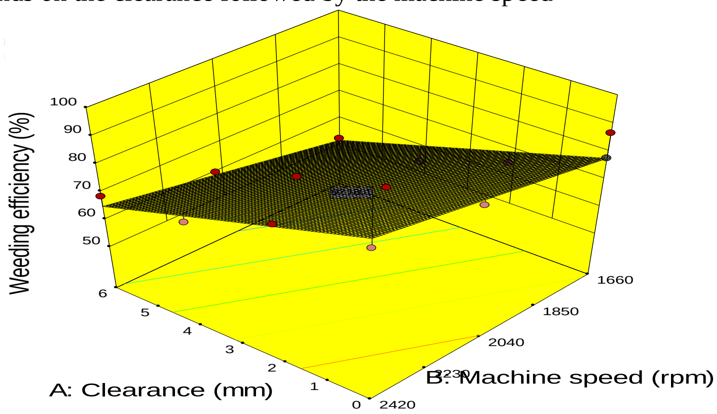

Figure 4: Effect of Machine Speed and Clearance on the Weeding Efficiency of the Mechanical Rotary Hoe

Table 3: Analysis of Variance (ANOVA) for the Weeding Efficiency of the Mechanical Rotary Hoe

Source	Sum of Squares	df	Mean Square	F Value	p-value (Prob > F)	Remark
Model	1593.519	2	796.760	41.098	0.000	significant
A-Clearance	1197.067	1	1197.067	61.747	0.000	
B-Machine speed	396.453	1	396.453	20.450	0.001	

3.2 Weeding Capacity

Figure 5 shows the weeding capacity of the developed machine. The weeding capacity ranges from 43.2 m^2/h - 129.6 m^2/h. The maximum value (129.6 m^2/h) of the weeding capacity was recorded at machine speed and clearance of 2420 rpm and 4 mm respectively, meanwhile, the minimum value (43.2 m^2/h) of the weeding capacity was recorded at machine speed and clearance of 1660 rpm and 6 mm respectively. The value obtained in this study is significantly higher than the result (10 –40m^2/h) reported by [6] for manually operated rotary weeder for a dry land crop, the higher weeding capacity that was obtained in this study might be due to the introduction of mechanical prime mover in the design. However, the values were in close range to the value reported for power weeder by the [9], [18], [24] – [29] while lower weeding capacity was reported for push-type, hand khurpi, power weeder, and cycle weeder in the same study.

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The mathematical relationship between the weeding capacity and the input parameter (clearance and machine speed) is shown in Equation 24 with a determination coefficient of 0.8505 and this shows that the equation can significantly (P<0.05) predict the 85.05% change in the weeding capacity as a function of machine speed and clearance.

$$WC \ = 0.4 - 24.86C + 0.04S + 0.013CS \qquad (24)$$

where WC is the weeding capacity, C is the clearance (mm) and S is the machine speed (rpm)

Table 4 shows the result of the Analysis of Variance (ANOVA) of the weeding capacity, based on the table, the combination of machine speed and clearance can significantly explain the variation in the weeding capacity at a 99% probability level. However, the change in the weeding capacity significantly (P<0.05) depends on the machine speed followed by the clearance. This is in agreement with the observation by [24].

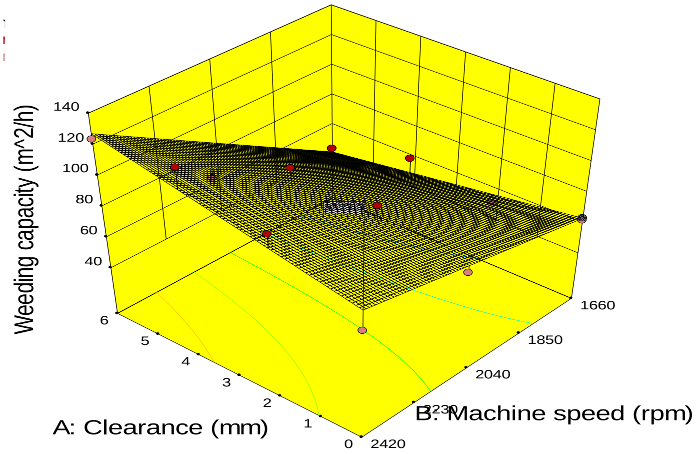

Figure 5: Effect of Machine Speed and Clearance on the Weeding Capacity of the Rotary Hoe

Table 4**:** Analysis of Variance (ANOVA) for the Weeding Capacity of the Rotary Hoe

Source	Sum of Squares	df	Mean Square	F Value	p-value (Prob > F)	Remark
Model	7753.733	3	2584.578	15.172	0.001	Significant
A-Clearance	53.554	1	53.554	0.314	0.590	
B-Machine speed	6751.618	1	6751.618	39.633	0.000	

3.3 Uncleared Weed

Figure 6 shows the uncleared weed of the developed machine. According to Figure 5, the uncleared weed ranges from 11% - 48%. The maximum value (48%) of the uncleared weed was recorded at machine speed and clearance of 1660 rpm and 6 mm respectively, meanwhile, the minimum value (11%) of the uncleared weed was recorded at machine speed and clearance of respectively 2420 rpm and 0 mm. the result of uncleared weed in this study is in a close range the value (45.02% to 40.95%) at a cutting speed of 1804 rpm to 2261 rpm as reported by [14] during the design, fabrication and evaluation of a rotary power weeder and higher than the value deduced from the report by [8], [23], [29].

The mathematical relationship between the uncleared weed and the input parameter (clearance and machine speed) is shown in Equation 25 with a determination coefficient of 0.9013 and this shows that the equation can significantly (P<0.05) predict the 90.13% change in the uncleared weed as a function of machine speed and clearance. The uncleared weed increases as the clearance increases while the machine speed decreases.

$$UCW \ = 52.57 + 4.47C - 0.02S \qquad (25)$$

where UCW is the uncleared weed, C is the clearance (mm) and S is the machine speed (rpm)

Table 5 shows the result of the analysis of variance (ANOVA) of the uncleared weed. Based on the table, the combination of machine speed and clearance can significantly explain the variation in the uncleared weed at a 95% probability level similar observation was deduced from the findings of [23]. However, the change in the uncleared weed significantly (P<0.05) depends on the machine speed followed by the clearance

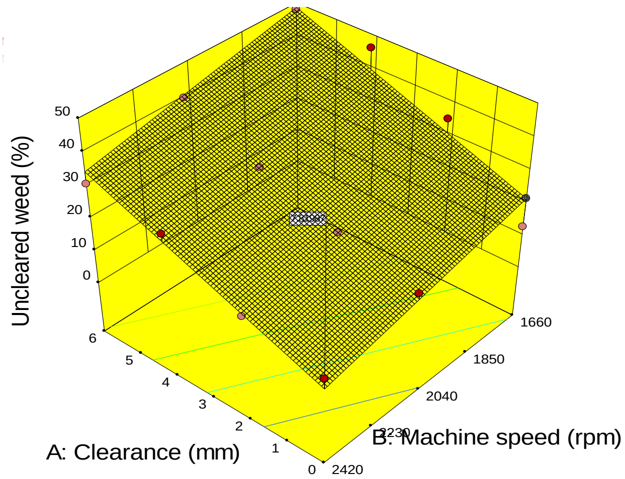

Figure 6: Effect of Machine Speed and Clearance on the Uncleared Weed by the Mechanical Rotary Hoe

Table 5: Analysis of variance (ANOVA) for the uncleared weed by the rotary hoe

Source	Sum of Squares	df	Mean Square	F Value	p-value (Prob> F)	Remark
Model	1593.52	2	796.76	41.1	< 0.0001	Significant
A-Clearance	1197.07	1	1197.07	61.75	< 0.0001	
B-Machine speed	396.45	1	396.45	20.45	0.0014	

3.4 Tilling Efficiency

Figure 7 shows the tilling efficiency of the developed machine. According to the figure, the tilling efficiency ranges from 5% - 79%. The maximum value (79%) of the tilling efficiency was recorded at machine speed and clearance of 2420 rpm and 0 mm respectively, meanwhile, the minimum value (5%) of the tilling efficiency was recorded at machine speed and clearance of respectively 2420 rpm and 6 mm.

The mathematical relationship between the tilling efficiency and the input parameter (clearance and machine speed) is shown in Equation 26 with a determination coefficient of 0.9914 and this shows that the equation can significantly (P<0.05) predict the 99.14% change in the tilling efficiency as a function of machine speed and clearance.

$$TE = 76.4 - 12.99C - 0.02S - 0.003CS + 1.4C^2 \quad (26)$$

where TE is the tilling efficiency, C is the clearance (mm) and S is the machine speed (rpm)

Table 6 shows the result of the analysis of variance (ANOVA) of the tilling efficiency, based on the table, the combination of machine speed and clearance can significantly explain the variation in the tilling efficiency at a 95% probability level. However, the change in the tilling efficiency significantly (P<0.05) depends on the machine speed followed by the clearance

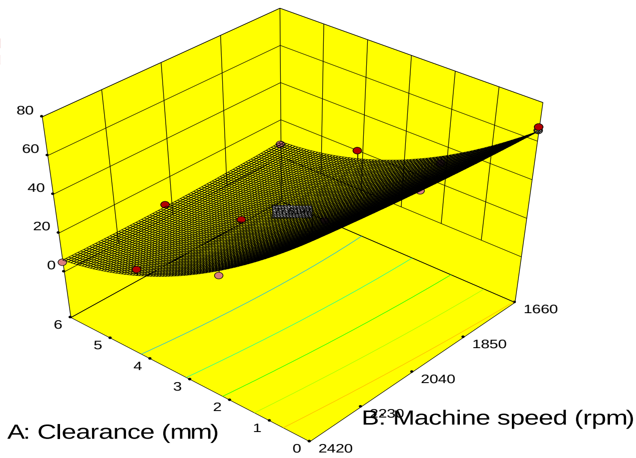

Figure 7: Effect of machine speed and clearance on the tilling efficiency of the rotary hoe

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Table 6: Analysis of variance (ANOVA) for the tilling efficiency of the rotary hoe

Source	Sum of Squares	df	Mean Square	F Value	p-value (Prob > F)	Remark
Model	7402.74	5	1480.55	138.43	< 0.0001	Significant
A-Clearance	6869.82	1	6869.82	642.32	< 0.0001	
B-Machine speed	40.5	1	40.5	3.79	0.0996	

3.5 Tilling Capacity

Figure 8 shows the tilling capacity of the developed machine. According to the figure, the tilling capacity ranges from 5.82 m²/h - 71.1 m²/h. The maximum value (71.1 m²/h) of the tilling capacity was recorded at machine speed and clearance of 2420 rpm and 0 mm respectively, meanwhile, the minimum value (5.82 m²/h) of the tilling capacity was recorded at machine speed of 1660 rpm and clearance of 6 mm respectively.

The mathematical relationship between the tilling capacity and the input parameter (clearance and machine speed) is shown in Equation 27 with a determination coefficient of 0.9704 and this shows that the equation can significantly (P<0.05) predict the 97.04% change in the Tilling capacity as a function of machine speed and clearance.

$$TC = -16.15 + 0.85C + 0.04S - 0.0046CS \qquad (27)$$

where TC is the tilling capacity, C is the clearance (mm) and S is the machine speed (rpm)

Table 7 shows the result of the analysis of variance (ANOVA) of the tilling capacity, based on the table, the combination of machine speed and clearance can significantly explain the variation in the Tilling capacity at a 95% probability level. However, the change in the Tilling capacity significantly (P<0.05) depends on the machine speed followed by the clearance

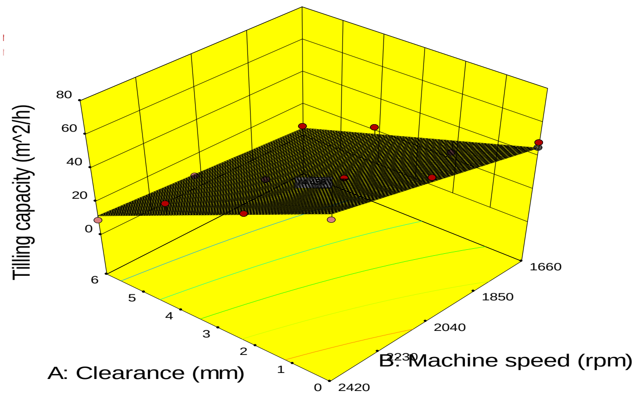

Figure 8: Effect of machine speed and clearance on the tilling capacity of the rotary hoe

Table 7: Analysis of variance (ANOVA) for the tilling capacity of the rotary hoe

Source	Sum of Squares	df	Mean Square	F Value	p-value (Prob > F)	Remark
Model	5294.19	3	1764.73	87.33	< 0.0001	Significant
A-Clearance	4455.98	1	4455.98	220.52	< 0.0001	
B-Machine speed	640.53	1	640.53	31.7	0.0005	

3.6 Optimal performance of the rotary hoe

Table 8 shows the optimal goal and range of optimality for the developed rotary hoe. The table shows the range of optimality for the developed mechanical rotary hoe as 0.00 mm - 6.00 mm, 1660.00 rpm -2420.00 rpm, 52.00% - 89.00%, 11.00 % - 48.00%, and 43.20 m^2/h - 129.60 m^2/h for the blade clearance, machine speed, weeding efficiency, uncleared weed and weeding capacity respectively to maximize the blade clearance, machine speed, weeding efficiency and weeding capacity while the uncleared weed with minimizing with the blade clearance and machine speed set in range.

Table 9 depicts the optimal performance of the mechanical rotary hoe. The mechanical rotary hoe is best operated under the optimal condition of 0.00mm and 2420 rpm for the blade clearance and machine speed respectively and obtain optimal performance of 92.18%, 7.82%, and 93.23 m^2/h for weeding efficiency, uncleared weed, and weeding capacity respectively with the highest desirability of 0.893.

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Table 8: Optimal goal and range of optimality for the developed rotary hoe

Parameter	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
A: Clearance (mm)	is in range	0.00	6.00	1	1	3
B: Machine speed (rpm)	is in range	1660.00	2420.00	1	1	3
Weeding efficiency (%)	maximize	52.00	89.00	1	1	3
Uncleared weed (%)	minimize	11.00	48.00	1	1	3
Weeding capacity (m^2/h)	maximize	43.20	129.60	1	1	3

Table 9: The optimal performance of the rotary hoe

S/N	Clearance	Machine speed	Weeding efficiency	Uncleared weed	Weeding capacity	Desirability	Remark
1	0.000	2420.00	92.18	7.82	93.23	0.893	Selected
2	0.000	2414.22	92.07	7.93	93.01	0.892	
3	0.068	2420.00	91.88	8.12	93.62	0.891	
4	0.000	2400.92	91.83	8.17	92.50	0.889	
5	0.125	2420.00	91.62	8.38	93.95	0.889	
6	0.189	2420.00	91.34	8.66	94.32	0.887	
7	0.000	2390.17	91.63	8.37	92.09	0.887	
8	0.000	2317.76	90.29	9.71	89.31	0.872	

4. CONCLUSION

The weeding efficiency, weeding capacity of the rotary hoe ranges from 52% - 89%, 43.2 m²/h - 129.6 m²/h. The combination of machine speed and clearance can significantly predict about 90.13% 85.05% and 90.13% change in the weeding efficiency weeding capacity and uncleared weed respectively. The optimal performance of the hoe was 92.18%, 7.82%, and 93.23 m2/h for weeding efficiency, uncleared weed, and weeding capacity respectively with the highest desirability of 89.3% when operated at a machine speed of 2420 rpm and 0mm clearance. In the field, the rotary hoe should be operated at a machine speed of 2420 rpm and 0mm clearance to maximize the weeding efficiency, weeding capacity and minimize the uncleared weed. This machine can be used for land infested mostly with weeds like Tridax procumbex, Sida acuta, and Eleusine indicae.

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