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Development of a Semi-Automatic Hand-Pushed Weeder

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Abstract: *When farmers plant their crops, as the crops are germinating, unwanted plants grow in between them thereby increasing plant population density and competing for nutrients with the main crops and reducing yield at harvest. Farm crop yield reduction due to weeds alone is estimated to be 16 – 42% depending on the crop and accessibility of the location. In developing countries, such as Nigeria, mechanized farming is not common, it is manual labour or semi-mechanized farming that are prevalent. Manual labour can involve up to one-third of the cost of cultivation. Some farmers employ the use of herbicides. In this paper, semi-automated hand-pushed weeder that is cost-effective and less stressful for weeding operations in small-sized farms is developed. The weeder is developed to be used by farmers to replace manual labour, which is time-consuming, stressful, and costly. This weeder will reduce the cost of weeding operation and eliminate the environmental damage caused using herbicides to control weeds in farming and increase organically grown agricultural products as demand for non-chemical weeding increases. The weeder consists mainly of a 5 hp two-strokes petrol engine, with 2 – and 4 – interchangeable sets of weeding blades, and gear transmission system. The weeding blades are L-shaped and were mounted on a horizontal shaft, driven by an attachment through connection to the gearbox, which transmitted the rotary motion of the engine to the blades, 2- or 4- sets of blades were used to perform the task of weeding while the operator pushes the weeder during weeding operations. Tests were carried out to evaluate the machine based on fuel consumption and theoretical field capacity on soil with the moisture content of 7.5% and 13.5% at three different engine speeds of 1,500, 3,000, and 4,000 rpms. During the tests, it was discovered that, with the use of two sets of weeding blades at 1,500 rpm and soil moisture content of 7.5%, the fuel consumption was 1.52 l/h with theoretical field capacity of 0.56 m^2/s. For 4- sets of weeding blades at an engine speed of 4,000 rpm and soil moisture content of 13.5%, the maximum fuel consumption of 1.84 l/h and theoretical field capacity of 3.00 m^2/s were observed. In conclusion, it was discovered that using four sets of weeding blades at a speed of 4,000 rpm maximizes theoretical field capacity and minimizes the fuel consumption.*

Keywords: *Semi-automatic weeder, herbicides, manual labour, semi-mechanized farming, weed control.*

1. INTRODUCTION

Weeds are any unwanted plants that grow in undesired locations to compete for survival with desired plants. The world cannot survive without food. In developing countries, mechanized farming is not common, it is manual labour or semi-mechanized farming that is prevalent. When farmers plant their crops, as the crops are germinating, unwanted plants (weeds) grow in between them thereby increasing plant population density and competing for nutrients with the main crops and reducing yield at harvest. Crop yield reduction due to weeds alone is estimated to be 16 – 42% depending on the crop involved and farm location. Weeds control may involve up to one-third of the total cost of cultivation of the farm [1]. Agricultural losses to weeds competition are estimated to be about 13% if control measures are taken by farmers or more than 30 % in some cases when timely interventions are not employed [2].

There are various ways of getting rid of weeds but the most effective way of managing the weeds is by making direct contact with the weeds themselves [3]. This direct contact with the weeds could be achieved manually, chemically, or mechanically. The most popular weeding method (traditional African style) in Nigeria and most other developing countries is by using hand hoe which falls under "manual weeding operations". This type of weeding is achieved at low cost but involves intense labour and it is time-consuming. This is one of the major setbacks of traditional farmers in dealing with weeds in developing countries. Nkakini et al. [4] noted that it would be difficult for a farmer who uses only hand hoe for weeding to escape poverty because this type of technology appears to perpetuate human drudgery, danger, and misery. Another method of getting rid of weeds is by using herbicides. Herbicides could be pre-emergence or post-emergence. The implementation of conservation tillage practices to promote soil quality, minimize soil erosion or simplify crop management has increased reliance on herbicides [5]. However, renewed interests in mechanical weeding have grown due to environmental concerns in the use of chemicals, and growing demand for chemical-free farm produce, and the growth of chemical-resistant weeds [6]. Mechanical weed control with intelligent weeders has also been suggested as one of the effective techniques against chemical-resistant weeds [7].

Many works had been done in the area of mechanical weeding. Olukunle & Oguntunde [8] designed, fabricated, and tested a crop row weeder. The weeder reduced the labour required in row crop weeding, and it is a simple, cost-effective, and helpful machine for small to medium sized farms. It has a cutting height of 2 to 4 cm above the ground but works effectively as a weeder between the cutting height of 2 – 1 cm, which implies that it has a low cutting depth. Manuwa & Olofinkua [9] developed and carried out performance evaluation of a mechanical weeder in Southwestern Nigeria. The main features of the weeder were, a 5 hp internal combustion (IC) petrol engine as prime mover, power transmission system, three sets of weeding blades, mainframe, and ground wheels. A clutch safety mechanism was not used, and the handle of the machine was relatively short and had no adjustments. Muhammed and Atanda [10] designed, from locally sourced materials, a mechanical weeder that consists of two sets of cone rotor blades, an adjustable mainframe, and a float. This machine is like an immediate advanced weeding system of using hand tools (hoes and hand weeder). It made weeding easier but was still going to require high human power before weeding operation, soil loosening and weed burying can be completed. The machine can only work on a field with high soil moisture content of 40.8 % or higher, which can also be a significant problem especially on dry farms. Pushpavalli [11] developed a semi-automatic weeder. This was designed and developed as an improvement on an existing manual weeder by incorporating a petrol engine, sprockets, shaft, chain, and gears with few modifications on the mainframe. The handle is made in a way that, it can be adjusted to the operator's height. Handle grip is provided to hold the device in an appropriate position for easy operation. There is throttling lever fixed at the right side near the handle grip so that, the operator can actuate the lever easily. Some of the machine limitations were the use of too many chains and sprockets which can be a threat to growing crops, and lastly, no safety mechanism such as clutch was included. Bhongade et al., [12] designed and fabricated a battery-operated weeder and sprayer, an existing wheel weeder was powered electrically with the use of an electric motor and a battery which aimed to reduce the manual labour required in pushing the weeder. The weeder comprised of an electric motor, battery, switch, and mechanical joint. All these components were incorporated into an existing weeder. But the battery drained fast, therefore, it cannot be used for a long time on farmland where there is no source of electricity for charging the battery. Also, the weeder's inability to work in rough terrains is another limitation. Adetola & Odu [13] designed, manufactured, and evaluated a hand-push weeder for cutting weeds. The machine's principal components were the weeding drum, frame, and adjustable handle, all of which were made of mild steel. The transmission system consisted of belts and pulley mechanisms, as well as two wheels at the front and rear to aid the machine's mobility. This machine engages the weeding blades as soon as the engine starts because it has no safety feature in it, and it can only be used on small farms. Saravanakumar et al., [14], fabricated and evaluated a farmer friendly electric weeder. The weeder is powered electrically with the use of two batteries and a DC motor. The torque is transmitted from the electric motor to the C-shaped blades through a chain and sprocket transmission system. The weeder had some drawbacks, such as two short handles that are not adjustable, and the weeder's inability to work in rough terrains. Devanathan et al., [15], designed and developed a cost-effective agricultural weeder for small-scale weeding. The electric motor, batteries, J-shaped blades, and a frame are the main components of the machine. The weeder works in a similar way like two hoes, weeding side by side. The machine has stability concerns and is slow due to the J-blade mechanism. It has large spacings between the J blades, the weeder can't work where electricity supply is not constant for recharging the batteries. The objective of this paper is to develop a hand-pushed semi-automatic weeder that is portable and more effective than earlier versions, intended for use in any terrain. A 2-stroke 5 hp internal combustion petrol engine with three variable speeds is used to power it. It has a clutch mechanism as its safety device, two long adjustable handles which can be adjusted to operator's height and desire, and a gearbox to change torque and speed of the weeder during weeding operation.

2. MATERIALS AND METHODS

2.1. Materials

The hand-pushed weeder is composed mainly of four parts, namely: five horsepower (5 hp) internal combustion (IC) petrol engine, the frame, cutting blades, and the gearbox, with other peripheral parts such as clutch, wheels, handles, shafts, and pulleys. The peripheral components of the weeder are there to help improve the working efficiency and safe operation of the device. The major component of the weeder and its function are listed below.

2.1.1. Frame

The frame has a length of 520 mm, a width of 105 mm, and it is 66.5 mm in height, made from 32.5 mm (1 ¼ inch) angle bar mild steel. The frame serves as the chassis for the attachment of the other components of the weeder. The schematic drawing of the frame is shown in Figure 1 (a & b). It shows a simple frame design with slots and holes for the attachment of other parts.

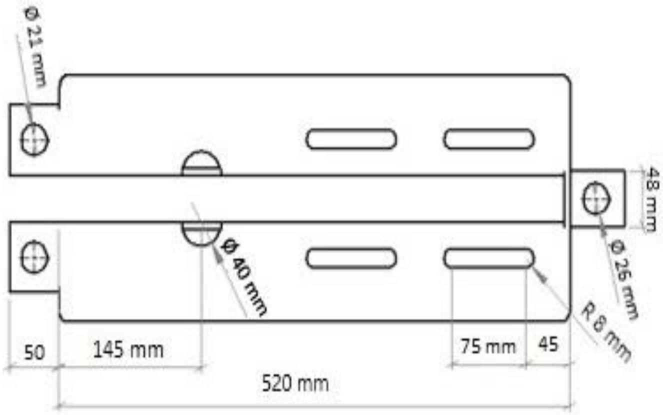

Figure 1a: 2D Drawing of the frame

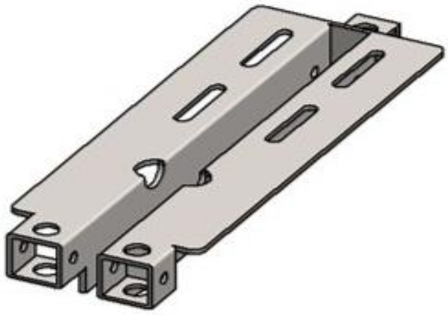

Figure 1b: 3D Drawing of the frame

2.1.2. Cutting blade

The cutting blades used in this weeder were L-shaped type made from mild steel that were inspired by the farming hoe, to have high weeding efficiency [16]. These blades do not only serve the purpose of weeding but are also used as makeshift wheels support for the weeder. The implementation of a hoe design on the blade was made to ensure that the weeder also tills the soil while weeding thus making planting easier for the farmer. A set of blades consists of four cutters arranged at right angles to each other. A schematic diagram showing the shape and dimensions of a cutting blade is shown in Figure 2.

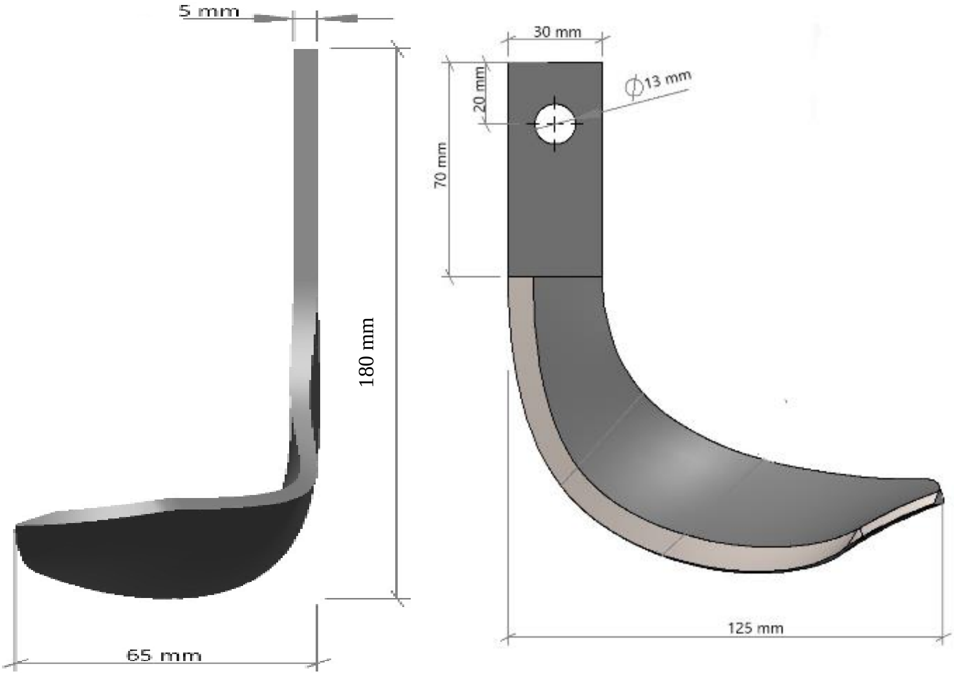

Figure 2: The Cutting Blade

2.1.3. The gearbox

The gearbox shown in Figure 3, is a set of gears with its housing meant to transfer energy from the petrol engine to the shaft and subsequently to the cutting blades. The purpose of the gearbox is to reduce the speed transmitted from the engine in the ratio of 30:1. It is also used to vary the speed and the torque output from the petrol engine. The input speed and desired output speed were used to determine the gear ratio required. The service factor, gearbox mounting, and gearbox shaft were all factors considered when choosing the gearbox. From design calculations, given the maximum weeder's operating speed, a gearbox with a gear ratio of 30:1 was selected. The gearbox was bought from the local market, mounted on the frame and coupled to the petrol engine. The gearbox is connected to the engine with a pulley and belt transmission system, the gearbox has a dimension of 417 mm x 40 mm and it is shown in Figure 3.

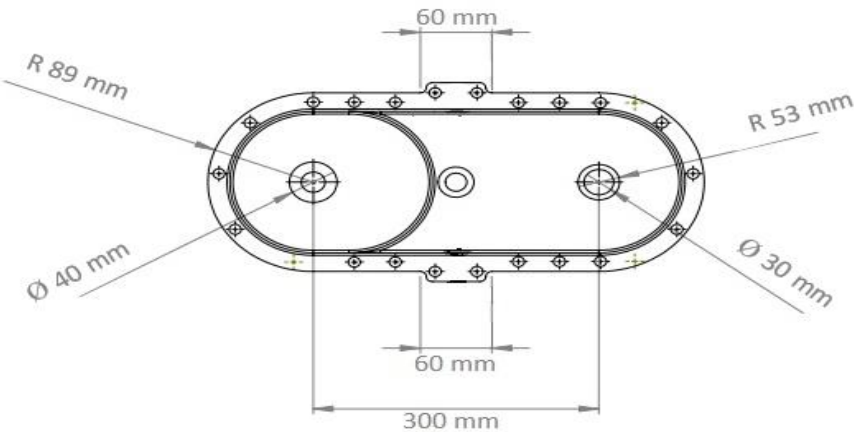

Figure 3: Drawing of the gearbox

2.1.4. The engine

The internal combustion petrol engine acquired for the project is a 3.3 kW (5 hp), two-stroke petrol engine that runs at three speeds. The engine came with three predetermined speeds of 1, 500, 3, 000 and 4, 000 rpms. These engine speeds were confirmed with handheld tachometer. The engine transmits power to the gearbox through a belt and pulley system. The engine is the only source of power of the weeder. The engine can operate in any of these speeds.

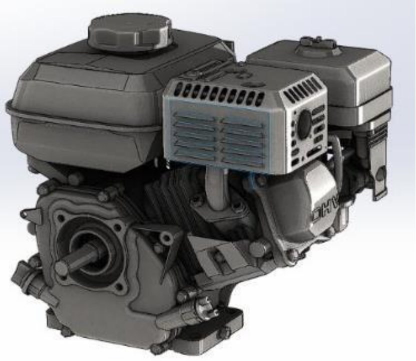

Figure 4: Two-stroke internal combustion petrol engine

2.1.5. The clutch

The clutch is a safety mechanism that is used to engage and disengage the blades and the engine when the operator is about to start and at the end of weeding operation.

2.2. Methods

The hand-pushed semi-automatic weeder was developed based on some factors, such as appropriate materials that are both low cost and structural stability, and simple assembly of components to allow for easy maintenance. The cost, availability, durability, total weight, and affordability were all factors considered in the selection of the materials. The weeder was constructed with mild steel and expected to target weed control at the early stage while also tilling the soil in the process. The weeder's power requirement, and the types of weeds to be operated on, were all considered when designing the blade. Figure 5 shows a 3D assembly design of the hand-held semi-automatic weeder. Figure 6 is the exploded view while the list of parts used in construction were given in Table 1.

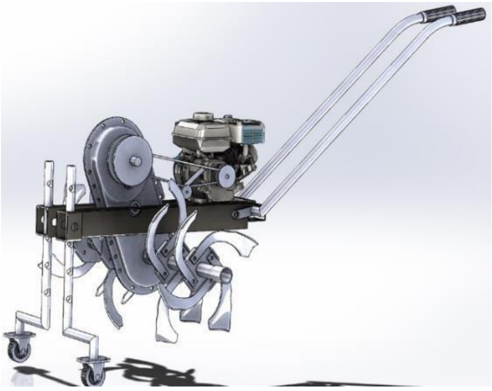

Figure 5: 3D design of the hand-held automatic weeder

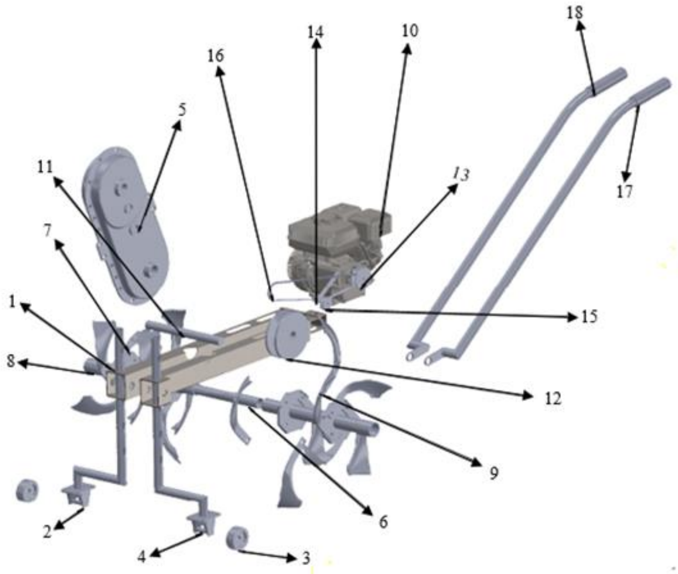

Figure 6: 3D exploded view of the hand-pushed automatic weeder

Table 1: Part names for Weeder's exploded view in figure 6

ITEM NO.	PART NO	QTY.
1	Frame	1
2	Wheel holder	2
3	Wheel	2
4	Wheel shaft	2
5	Gearbox	1
6	Blade Shaft	1
7	Blade Left	2
8	Blade hub	4
9	Blade Right	2
10	Engine	1
11	Pulley shaft	1
12	Gearbox Pulley	1
13	Engine Pulley	1
14	Clutch Handle	1
15	Clutch Pulley	1
16	Pulley Belt	1
17	Handle	2
18	Handle Grip	2

2.3. Design Analysis

2.3.1. Engine power requirement

The total engine power, P_t, required by the weeder is given in Equation (1) [17]

$$p_t = \frac{p_d}{\eta} \quad (1)$$

where

p_t = Total power
p_d = Draft power
η = Efficiency

The draft power, P_d, is obtained from Equation (2) [17]

$$p_d = \frac{SR \times d \times w \times v}{75} \tag{2}$$

where

SR = soil resistance in kgf/cm^2 = $1kgf/cm^2$
d = depth of cut in cm = 6 cm
w = effective width of cut in cm = 45mm =45 x 2 x 4 = 360mm =36cm
v = speed of operation in ms^{-1} = 1.2 ms^{-1}

To obtain the draft power, p_d, with a maximum soil resistance of 1 kgf/cm^2 (98.0665 kpa), the required range of speed of operation is 0.9 ms^{-1} to 1.2 ms^{-1}, blade width of 350 mm, the depth of operation between 30 and 60 mm and the efficiency of the machine assumed to be at 80%. The maximum speed of operation of 1.2 ms^{-1} was selected based on [18] and the engine used, to ensure effectiveness of the machine. Therefore, the draft power and total power are given in Equations (3) and (4) respectively:

$$P_d = \frac{1 \times 6 \times 36 \times 1.2}{75} \tag{3}$$

$$= \frac{1 \times 6 \times 36 \times 1.2}{75}$$

$$= 3.46hp$$

$$P_t = \frac{P_d}{\eta} \tag{4}$$

$$= \frac{3.46}{0.8}$$

$$= 4.3\ hp$$

$$= 3.2\ kw$$

The weeder requires an estimated engine power of 3.2 kW to operate at 80% efficiency. A 3.3 kW, two-stroke petrol engine with adjustable 3 speeds was acquired for this work.

2.3.2 Power transmission design

2.3.2.1 Pulley sizing

To calculate the sizes of the pulley, manufacturer data were considered. The engine rotates at 4,000 rpm and is prefixed with an 83 mm diameter pulley. The maximum forward speed of the machine is 1.2 m/s. Assuming the speed to be given to the gearbox pulley is 2160 rpm, the gear pulley diameter is obtained from Equation (5) [19]:

$$\text{Velocity ratio} = \frac{N_1}{N_2} = \frac{d_2}{d_1} \tag{5}$$

where N_1 = Speed of engine in rpm = 4000 rpm
N_2 = Initial gear box speed in rpm = 2160 rpm
d_1 = engine pulley diameter = 83 mm
d_2 = gearbox pulley diameter = to be determined

$$d_2 = \frac{4000 \times 84}{2160}$$

$$d_2 = 153.7\ mm$$

Therefore, the diameter of the gearbox pulley is assumed to be = 154 mm

2.3.2.2 Belt sizing

The total length of the belt required is calculated using Equation (6) [20]:

$$L = 2C + \frac{\pi(D+d)}{2} + \frac{(D+d)^2}{4C} \tag{6}$$

where

C = Centre distance (mm) = 900 mm
L = length of belt (mm) = ?
D = diameter of big pulley (mm) = 154 mm
d = diameter of small pulley (mm) = 83 mm

$$L = 2(900) + \frac{\pi(154+83)}{2} + \frac{(154+83)^2}{4(900)} = 2188mm$$

The velocity, v, of the belt is obtained from Equation (7):

$$v = \frac{\pi dn}{60*1000} \tag{7}$$

$$v = \frac{\pi * 83 * 4000}{60 * 1000}$$

$$v = 17.39\ m/s$$

The wrap angle (αs) of the small pulley is obtained from Equation (8):

$$\alpha_s = 180 - 2sin^{-1}\left(\frac{D-d}{2C}\right) \tag{8}$$

$$= 180 - 2sin^{-1}\left(\frac{154-83}{2*900}\right)$$

$$= \ 175.47° = 3.06\ radians$$

2.3.2.3 Gearbox requirement

Gearbox is used to control and reduce the speed of the engine to the cutter. Assumptions had been made to arrive at required dimensions in the design for the belt drive. The diameter of the gearbox initial pulley has been calculated to be 154 mm and input speed is 2160 rpm, blade diameter is 320 mm and actual speed ranges from 0.9 m/s to 1.2 m/s. The gear speed ratio is obtained from Equation (9) [20]:

Speed of driver

$$\text{Speed ratio} = \frac{\textbf{speed of driver}}{\textbf{speed of driven}} \tag{9}$$

Speed of driver = 2160 rpm

To find speed of driven, Equation (10) is utilized

$$v = wr \tag{10}$$

Where v = 1.2 m/s and r = 160 mm = 0.16 m

$$w = \frac{v}{r} = \frac{1.2}{0.16} = 7.50\ rad/s$$

Equation (11) is used to obtain the required gearbox speed in rpm,

$$w = \frac{2\pi N}{60} \tag{11}$$

$$N = \frac{60 \times w}{2\pi}$$

$$= 71.6 = 72\ rpm$$

From equation (9), the gearbox ratio is obtained. If the speed of driven pulley = 72 rpm, then,

$$speed\ Ratio = \frac{2160}{72}$$

Therefore, the gear ratio = 30:1

The gear ratio of the gear box is 30:1.

2.3.3 Shaft analysis

The torsional moment, T_m, must be less than $40MN/m^2$ [21] for a treated shaft to be regarded safe. The output shaft from the gearbox is treated and the torsional moment would be calculated using the power relation.

$$power = p = wT_m \tag{12}$$

where

P= Power = 3, 300 w

T_m= Torsional Moment

$$p = \frac{2\pi N}{60} \times T_m$$

But N= 4000 rpm

$$\therefore T_m = \frac{60\times3300}{2\times3.142\times4000} = 7.8771\ Nm$$

Maximum torsion is calculated using equation (13)

$$T_{max} = \frac{16T_m}{\pi {d_o}^3} \tag{13}$$

But $d_o = 25mm$

$$T_{max} = \frac{16 \times 7.8771}{3.142 \times (0.025)^3} = 2.57MN/m^2$$

2.3.4 Blade analysis

The material used in fabricating the blade is mild steel which has its properties as:

$S_y = Yield\ Strenth = 250\ MN/m^2$
$S_{ut} = Ultimate\ Tensile\ Strenth = 460\ MN/m^2$

Equation (14) was used to determine the allowable working stress,

$$\sigma_{allowable} = \frac{Yield\ Strength}{Factor\ of\ Saftey} = \frac{S_y}{n} \tag{14}$$

The factor of safety for shock load on steel ranges between 12 and 16, but the maximum value of 16 is used in equation (14) [19]. Using equation (14)

$$\sigma_{all} = \frac{250}{16} = 15.6\ MN/m^2$$

To comply with the ASME Code for commercial steel shafting [21], the maximum permitted working stress must be less than $40MN/m^2$.The material is safe to use, since $15.6\ MN/m^2 < 40MN/m^2$. The cutting blade rotates at a high angular velocity, when rotating, the blades appear like a revolving disc with a uniform radius and thickness. The velocity can be determined using equation (15)

$$\omega^2 = \frac{8\sigma}{(3+v)\rho\, r^2} \tag{15}$$

where

$\omega = permissible\ speed = 4000\ rpm = 418.9\ rad/s$
$v = poission\ ratio = 0.3$
$\rho = density\ of\ material = 7850\ kg/m^2$
$r = The\ Blade\ radius = ?$
$\delta = permissible\ stress = 15.6\ MN/m^2$

To calculate the radius of the blade, the following assumptions were made:

1) The stress is constant throughout the thickness of the blades
2) Stress concentration is neglected
3) The blade thickness is considered insignificant in comparison to the radius.

With these assumptions, then, equation (15) becomes equation (16)

$$r = \sqrt{\frac{8 \times \sigma_{all}}{(3+v)\rho\omega^2}} \tag{16}$$

$$= \sqrt{\frac{8\ \times\ 15.6\ \times\ 10^6}{(3 + 0.3)\ 7850 \times 418.9^2}} = 160\ mm$$

The radius of the blade is 160 mm, and the diameter will be 320 mm.

2.3.5 Design for the blade flange and bolt

2.3.5.1 The flange

The blades must be attached to the gearbox shaft via a coupling flange for weeding to occur, which necessitates the design of both the flange and the bolt that connects them. The bearing pressure of the bolt determines the flange thickness. The maximum torque capacity T_m is given in equation (18) as

$$T_m = S_B(d \times t)D_{bc} \times z \tag{17}$$

Where S_B = Allowable bearing Pressure
d = Bolt diameter
D_{bc} = Distance between two opposite bolts
t = flange thickness
z = number of bolts

Allowable stress for Carbon Steel Bearing = $S_B = 13.75kpsi = 94.8\ MN/m^2$

Diameter of hub = $D_H = 2d_o$
= 2 x 25 mm = 50mm

Diameter of Flange = h = 2 D_H
= 2 x 50mm = 100mm

Distance between two opposite bolts, i.e., Bolts Circle = D_{bc} is given in equation (18)

$$D_{bc} = D_H + \frac{h - D_H}{2} = \frac{h + D_H}{2} \tag{18}$$

$$= \frac{100 + 50}{2} = 75\ mm.$$

Number of Bolt = Z = 4 bolts
:. from equation (12)

Torque capacity, $T_m = 94.8\ \times 10^6 (0.013 \times 0.005) \times 0.075 \times 4$
= 1848.6 Nm

Flange thickness is calculated using equation (19)

$$t = \frac{2 \times T_m}{S_B \times d \times D_{bc} \times n} \tag{19}$$

But n = 2z = 2 x 4 = 8

$$= \frac{2 \times 1848.6}{94.8 \times 10^6 \times 0.013 \times 0.075 \times 8} = 5\ mm$$

The Flange thickness is 5 mm.

2.3.5.2 Bolt design

The coupling flange is connected to the cutting blade by bolts. The bolt can be analysed in one of these several ways:

1). In torsion, both the bolts and the shaft are assumed to have the same torque capacity.
2). Assume the bolts are finger tight and the load is transferred from the coupling to the blade via consistent shear stress in the bolts' shanks.
3). assuming the bolts are only finger tight, and the load is transferred from the coupling to the blade with maximum shear stress in the bolt shank equal to 3/4 times the average shear stress.

Equation (20) gives the expression to find maximum torque:

$$K_t M_t = S_s \left(\frac{\pi d^2}{4}\right) \left(\frac{D_{bc}}{2}\right) \times z \tag{20}$$

Where $M_t = T_{max}$ = the maximum torque
$K_t =$ factors of Safety
S_s = Stress for the shaft
$M_t = T_m = 1848.6\ Nm$
$S_s = T_{max}$
$K_t = \frac{4}{3} = 1.33 \qquad z = 4\ bolts$

$$M_t = \frac{3}{4} T_{max} \left(\frac{\pi d^2}{4}\right) \left(\frac{D_{bc}}{2}\right) \times z \tag{21}$$

$$1848.6 = 0.75 T_{max} \left(\frac{\pi d^2}{4}\right) \left(\frac{D_{bc}}{2}\right) \times z$$

$$1848.6 = 0.75T_{max} \times \left(\frac{\pi(0.013)^2}{4}\right)\left(\frac{0.075}{2}\right) \times 4$$

$$T_{max} = 123.78\ MN/m^2$$

For equation (21)

$$1848.6 = \frac{3}{4} \times 123.78 \times 10^6 \times \left(\frac{3.142 \times d^2}{4}\right)\left(\frac{0.075}{2}\right) \times 4$$

$$d = 13\ mm$$

The standard bolt size of 13 mm is M20 bolt.

2.3.6 Soil moisture test

Oven drying technique was used to conduct a soil test to determine soil moisture content. 5 kg of sand were gathered from the two locations of the weeder testing. They were weighed, and dried in the oven, and weighed again after drying to determine the percentage of soil moisture. Wet moisture percentage is obtained using Equation (22) [22],

$$M_w = \frac{W_w}{W_t} \times 100 \qquad (22)$$

where m_w = wet moisture percentage
w_w = weight of water
w_t = total weight of sand

First soil test (dry farmland)
w_w = weight of water = 5 – 4.635 = 0.365 kg
w_t = total weight of sand = 5kg
m_w = 7.3%

Second soil test (moist farmland)
w_w = weight of water = 5 – 4.325 = 0.675 kg
w_t = total weight of sand = 5 kg
m_w = 13.5 %

3. RESULTS AND DISCUSSIONS

The parts of the semi-automatic hand-pushed weeder were successfully designed and fabricated, then, they were coupled together as shown in Figure 7.

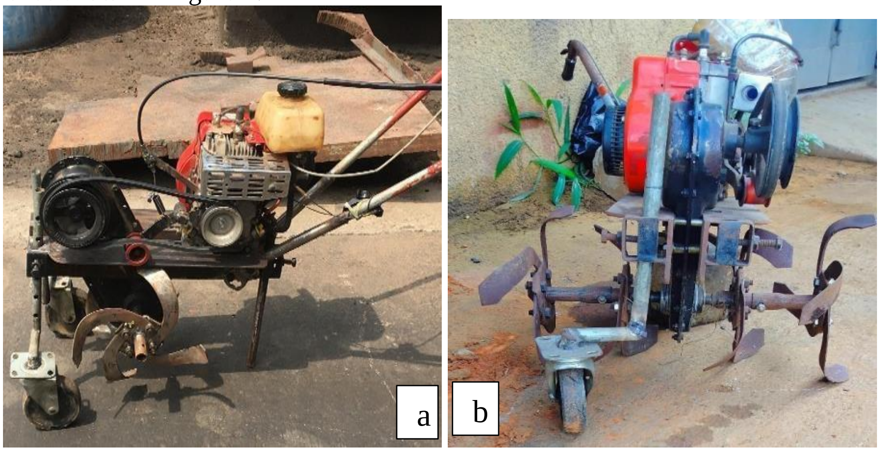

Figure 7: Assembled Fabricated Hand-pushed Weeder (a: 2 sets and b: 4 sets of blades)

The machine was tested in two different locations with different soil moistures to observe the performance and efficiency in terms of fuel consumption and theoretical field capacity. The machine was tested with two different blades configurations (2- and 4- sets of weeding blades). The speed of operation of the weeder was varied using the throttle installed on the machine handle. Two different farm locations were used for the testing, dry land with moisture content of 7.5 % and wetland close to river with moisture content of 13.5 % were worked upon.

3.1 Fuel Consumption

The fuel consumption test was carried out by filling the engine with 1,000 ml of fuel. A measuring jar was used to measure 1,000 ml of fuel, the fuel was poured into the machine tank. The tests were carried out with 2 sets of blades and 4 sets of blades on 7.5 % and 13.5 % soil moisture contents. Each test lasted for 30 minutes, after which the remaining fuel in the tank was drained, measured, and recorded as indicated in Table 2. It is clear in the results in Figure 8 that the fuel consumption increases as the speed of operation increases. Operations with 4 sets of blades consume more fuel than operations with 2 sets of blades at the two moisture contents. Fuel consumptions are higher in operations of soil contents of 7.5 % than in operations of 13.5 % soil moisture content. The minimum fuel consumption was 1.52 l/h and it was recorded when using 2- sets of weeding blades with an engine speed of 1,500 rpm on the soil with a moisture content of 13.5% while the maximum fuel consumption was obtained to be 1.84 l/h which was recorded at 4 - set of weeding blades with an engine speed of 4,000 rpm on the soil with a moisture content of 7.5 %.

Table 2: Fuel Consumption

Speed (RPM)	**Fuel consumption (ml)**			
	7.5 % soil moisture		13.5 % soil moisture	
	2 Sets of blades	**4 Sets of blades**	**2 Sets of blades**	**4 Sets of blades**
1,500	800	840	760	770
3,000	830	880	790	820
4,000	880	920	830	870

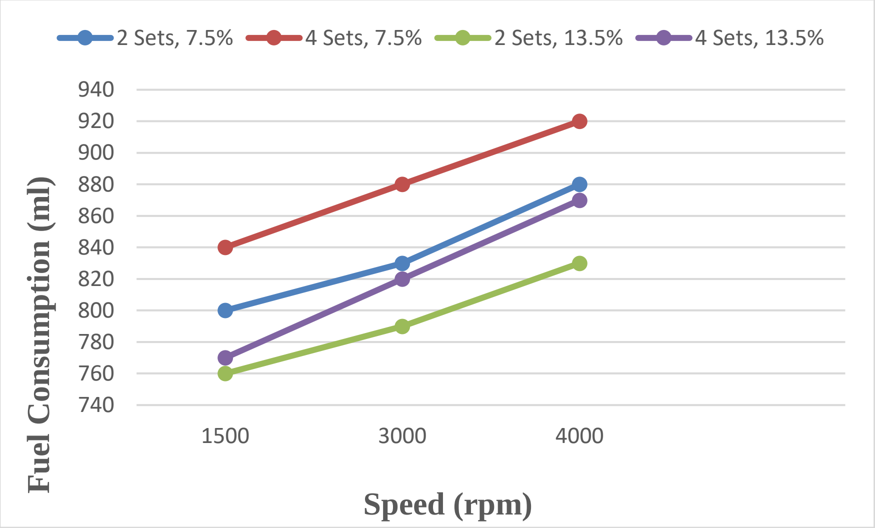

Figure 8: Graph of fuel consumption and speed for 7.5% and 13.5 % moisture contents

3.2. Theoretical Field Capacity

The theoretical field capacity (TFC) is calculated using Equation (23) [23, 24]. The TFC of the machine was computed as follows:

$$\text{TFC } (m^2/s) = \text{speed of weeding } (m/s) \times \text{effective width of weeding } (m) \qquad (23)$$

where the effective width of the blade = 65 mm = 0.065 m and the blade radius = 160 mm = 0.16 m. the effective width of blades for 2 sets and 4 sets of blades are 0.25 m (2 x 0.125 m) and 0.5 m (4 x 0.125 m) respectively. The field performance of the weeder (theoretical field performance) can be calculated for the three speeds of the engine by using equations (9), (10) and (23) in succession. Table 3 gives the field performances of the developed hand pushed weeder for the three engine speeds.

Table 3: Field performance of the Weeder

Engine speed (rpm)	**Cutting Speed (m/s)**	**Theoretical Field Capacity (m^2/s) 2 sets of blades**	**Theoretical Field Capacity (m^2/s) 4 sets of blades**
4, 000	11.52	1.50	3.00
3, 000	8.64	1.12	2.25
1,500	4.32	0.56	1.12

The theoretical field performance reduces as the engine speed reduces, although, the overall performance depends on the human operator as well.

4. CONCLUSION

A hand-pushed semi-automatic mechanical weeder for use on various soil types and at three different operating speeds was designed, fabricated, assembled, and tested. The weeder components using mild steel and components dimensions were also analysed to ensure that they were structurally safe for use. To comply with the ASME Code [21] for commercial steel shafting, the maximum permitted working stress of the material must be less than $40 MN/m^2$. The material is safe to use since the material used (the structural steel) complied with the ASME code for commercial Steel Shafting. During the testing, the maximum fuel consumption recorded by the machine was obtained using 4 blades configuration on soil with a moisture content of 7.5 % at engine speed of 4, 000 rpm. The highest theoretical field capacity (TFC) recorded was at the engine speed of 4,000 rpm which is 3.0 m^2/s. For better performance of the weeder, it is advised to use the 4 - sets of weeding blades configuration on soil with moisture content of 13.5 % or higher and engine speed of 4,000 rpm. Higher soil moisture content and higher engine speed resulted in higher field capacity.

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