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Research Article

Development of Adjustable Reciprocating Rotary Weeder

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Abstract
Weeding is a labor intensive agricultural unit operation that needs to be controlled to ensure profitable agricultural activities as uncontrolled weed will lean or damage your harvest. The use of various blades for weeding has been the research focus for decades, but the use of rotary blades is less reported and it formed the base of this project. A developed adjustable reciprocating blades weeder for effective weeding was developed to eliminate weeds without much damage to the crops and soils around them. Parametric equations were used to characterize the motion of the weeding tine's route. Particular focus was placed on the kinematic parameters, their interactions with the weed control machine parts coupled with the trajectory movement and speed of the front rotating tine for effective operations of the tillage equipment. These established the design standard for the machinery and tools, thus appropriating for earthmoving operations. In order to test the machine for dry land crops, spear grasses and shrubs areas were used. Weeding efficiency and weeding index of the weeder were assessed during the test. It was observed that as the speed of the machine increased the weeding index and weeding efficiency also increased.
Keywords: Machine Design, Rotary, Weeding, Weeding Efficiency.

1. Introduction

Plants regarded as weeds in a location are those that are considered objectionable. Weeds are nuisance and oppressor that force it-self into any environment suitable for existence. Any plant that grows in an unwelcome location is considered a weed. Any plant that grows incorrectly in a location at incorrect time and causes more harm than good is considered a weed (Olaoye *et al.,* 2012). Weed is any plant that grows in areas where it is not intended. People have sought to suppress weeds for variety of reasons during course of horticulture's lengthy human history. Weeding garbage causes farmers to squander an inordinate amount of time and money as it inhibits growth. A lot of research has been done on how to control weeds. According to a survey premature weeding lowers returns of overall investments in crop production while unchecked weed growth lowers yields of the main crops (Gobor and Schulze Lammers, 2007).

One of the most crucial operations of modern agriculture is weed control. Weeds can be controlled or eliminated in variety of ways such as mechanical, chemical, biological, cultural techniques etc. The type of weeds, disposal equipment at hand and how the process interacts with the environment all affect how effective a particular method will be. Techniques used on a golf course or in a public park may not be applicable to rangeland or a forest area for economical and ecological reasons. The use of herbicides and chemicals that are sprayed on a roadside to get rid of ugly weeds that pose a fire or traffic danger is not applicable in farming. Mulching which is used to manage weeds in private gardens is impractical on large farms. In any case weed control has developed into a very specialized field of work. Weed management courses are taught in universities and agricultural institutions while industries provide required technologies. To sustain high levels of crop output weed management is crucial (Encyclopaedia Britannica, Inc. 2022). In order to address the issue of frequent transmission failure Masood Ur Rahman *et al.,* (2015) studied a locally produced self-propelled rotary hoe, which was utilized for mechanical hoeing and weed management. It was found that the worn gear utilized in its transmission frequently failed as a result of gear tooth surface wear.

In his work, Jeevarathinam *et al.,* (2014) presented the design modification and development of rotavator blade by the (CAD) interrogation approach. This was done by adjusting the design as well as the material properties. The vital components of rotary tillage machines that work with the soil to prepare the ground and mix fertilizer are the blades, unlike in the conventional plows in which blades are susceptible to impact and cyclic stresses that cause fatigue failure. These blades interact with the soil in a different way and shorten the blade's life span. Consequently, it is essential to create a proper blade.

Shridhar (2013) developed single wheel multi use weeder that is manually operated and performs only normal weeding operations to cut small size weeds, but cannot work where stones and obstacles are (Gobor and Schulze Lammers, 2007). Chertkiattipol (2008) in his paper studied the performance of rotary power tiller. The rotary power tiller has advantages over the conventional implement due to the effect of its direct application to the soil engaging tool that rotates around a horizontal transverse axis to achieve both plowing and harrowing in a pass of machine on the field. This reduces the traction demanded for tractor driving wheels due to the ability of the soil working blades to provide some forward thrust. This type of rotary tiller was attached to the rear axle of a two-wheel drive tractor with the arrangement of rotary blades on rotary shaft that affect the soil cutting pattern of the rotary tiller.

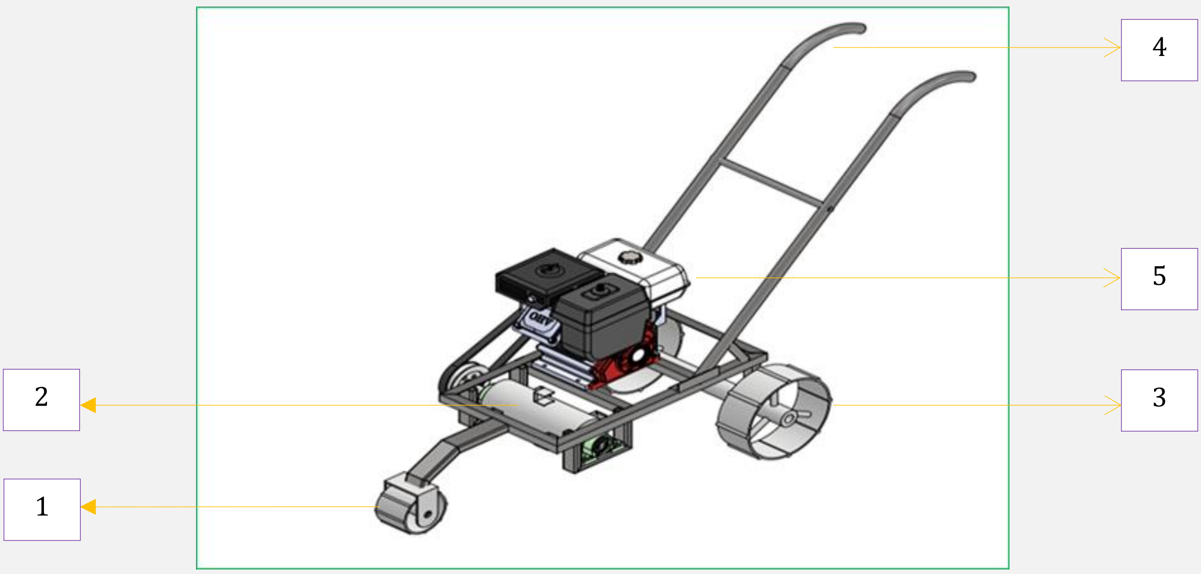
2. Methodology

2.1. Design Considerations

The design consideration approach of Ahmad (2012) was utilized in which he stated that in order to create an intra-row power operated weeder that is effective, the weeder should be aimed towards varied sized crop production and have an intra-row weed control efficiency of at least 80%. The weeder should also be able to control weeds with the least amount of agricultural plant damage possible while maintaining compact overall dimensions (Eng *et al.,* 2014).

2.2. Machine Components and Operation

The weeder was made up of the following parts: a frame, a tool assembly, four pneumatic ground wheels, and a handle. The weeder was powered by a prime mover which was connected to the rotary blades by a belt and pulley system (Figure 1). The rotary cylinder's operating component was the teeth which brake into the soil to loosen it and uproot the plants to remove the soil fragments. The rotation of the tine-carrying cylinder caused the plant materials to be uprooted.



1) Front wheel; 2) Tines; 3) Rear wheel; 4) Handle; 5) Prime mover

Figure 1. Schematic illustration of powered rotary weeder.

2.3. Machine Design Analysis

2.3.1. Kinematic Parameter (λ)

According to Sineokov (1965), all soil-working rotary tools must have kinematic parameter that is greater than one to successfully remove any weed. According to Oni (1990) the rotary tines' cutting angle (∈), rake angle (*r*), and angular motion (*w*) have impact on the kinematic characteristic of the rotary tines.

The tine has a velocity component V_{km} in relation to the weeder and a component V_f to the weeder's forward speed. The tine velocity, V_{kg}, in respect to the ground was obtained by adding the two vector components. The expression in equation 2.1 illustrates the relationship between the rake, bevel, and clearance angles.

$$\varnothing_{rk} + \varnothing_{bk} + \varnothing_{ck} = 90^0 \quad (2.1)$$

Where,
$\varnothing_{rk}$ = rake angle
$\varnothing_{bk}$ = bevel angle
$\varnothing_{ck}$ = clearance angle

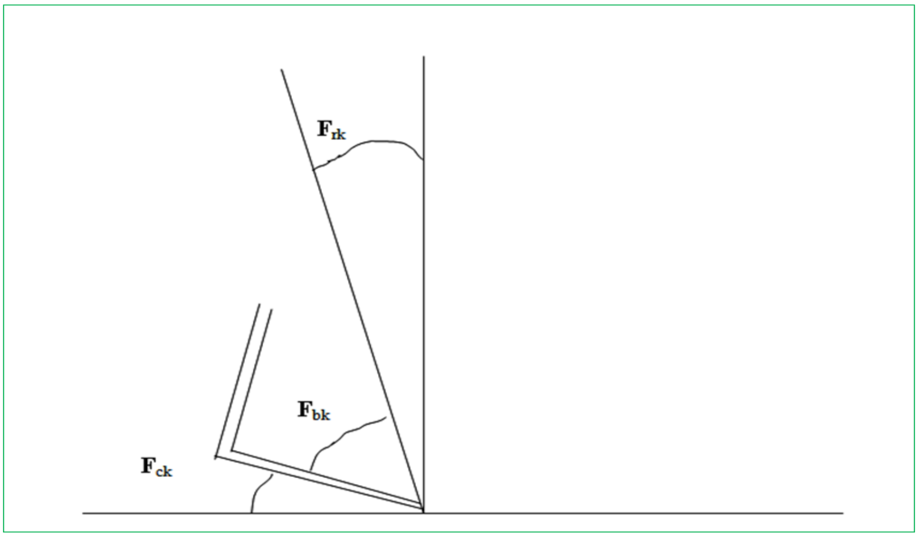


Figure 2. Illustration of tine geometry.

The locus has a point of inflection as the tines pierce the dirt, according to Odigboh and Ahmed (1979). Equation 2.2 demonstrates that the tine's absolute velocity in the x-direction is zero at this point.

$$\dot{x} = \frac{dx}{dt} = V_m - Rw \sin \phi = 0 \quad (2.2)$$

$$\sin \phi = \frac{V_m}{Rw} = \frac{1}{\lambda} \quad (2.3)$$

Hence, the equations 2.4 to 2.6 define kinematic parameter λ:

$$\lambda = \frac{Rw}{Vm} = \frac{1}{1-m} \quad (2.4)$$

$$\lambda = \frac{V_p}{V_f} \quad (2.5)$$

$$m = \frac{a}{R} V_f \quad (2.6)$$

Where,
ψ - *wt* angular rotation
V_p - the peripheral velocity of tip (m/s)
V_f - the forward velocity of weeder (m/s)
a - depth of cut by slice
λ -velocity ratio (or kinematic parameter)

2.3.2. Belt Design

The following factors were considered for belt selection: power rating of the prime mover, length of belt, the center distance, correction factors for belt and angle of wrap.

The center distance is the center between the two pulleys (engine pulley and machine pulley). It was determined by equation 2.7 and pitch length was given by equation 2.8.

$$C \geq \frac{D_1+D_2}{2} + 50 \text{ mm} \qquad (2.7)$$

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{(D_2-D_1)^2}{4C} \qquad (2.8)$$

Velocity ratio of two pulleys of a belt drive may be defined as number of revolutions per minute of the driving pulley divided by the number of revolutions per minute of the driven pulley. It is expressed as shown in equations 2.9 and 2.10.

The velocity of belt was determined by equation 2.9.

$$\text{Velocity ratio} = \frac{\text{diameter of driving pulley}}{\text{Diameter of driven pulley}}$$

$$= \frac{D2}{D1} \qquad (2.9)$$

$$= \frac{N2}{N1} \qquad (2.10)$$

Where,
D_1 = diameter of the driving pulley, mm
D_2 = diameter of the driven pulley, mm
N_1 = speed of the driving pulley, rpm
N_2 = speed of the driven pulley, rpm
C = centre distance, mm

$$\text{Velocity of belt} = \frac{\pi \text{ x Minimum pitch diameter x speed}}{60} \qquad (2.11)$$

Using the above equations
D_1 = 50 mm, N_2 = 600rpm
$D_2 = \frac{3600\ x\ 50}{600} = 300$ mm

$C \geq \frac{D_1+D_2}{2} + 50\text{mm}$
$C \geq \frac{50+300}{2} + 50\text{mm}$
$C \geq 255$ mm
∴ Let C = 250 mm

Belt velocity,
V = wr
But,
$w = \frac{2\pi N}{60}$

Hence,
$V = \frac{2\pi N}{60}$
$r = {}^{D}/_{2} = {}^{50}/_{2} = 25\text{mm} = 0.025$
V = 9.43 m/s

Belt length, using equation 2.8,

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

$$L = 2(250) + \frac{\pi}{2}(50 + 300) + \frac{(300 - 50)^2}{4(250)}$$
= 1112.35 mm

A V-belt of B-type 1210mm was preferred.
Contact angle, $\emptyset = 180\text{-}2\sin^{-1}$
$\emptyset = 120^0$

2.3.3. Pulley Selection

Diameter of engine pulley, $D_1 = 50mm = 0.05m$
Diameter of shaft pulley, $D_2 = 300mm = 0.3m$
Speed of engine, $N_1 = 3600rpm$
Speed of shaft, $N_2 = 600rpm$
Inner width of pulley, $b_1 = 0.011m$
Outer width of pulley, $b_2 = 0.013m$
Inner diameter of pulley, d = 0.03m

The solid volume of pulley was determined by equation 2.12.

The solid volume of pulley = $\frac{\pi d^2 b^2}{4}$ (2.12)

The solid volume of pulley $\frac{3.142(0.3)^2(0.013)^2}{4} = 9.19 \times 10^{-4}m^3$

The volume of the groove in the pulley and the volume of shaft pulley were given by the expressions in equations 2.13 and 2.14.

Volume of groove in pulley = $\frac{1}{2}(b1 + b2)d\pi D_2$ (2.13)
$= \frac{1}{2}(0.011 + 0.13) \times 0.3 \times 3.142 \times 0.3$
$= 3.39 \times 10^{-4}m^3$

Volume of shaft hollow = $\pi d^2 b_2/4$ (2.14)
$3.142 \times 0.032 \times 0.013/4 = 9.2 \times 10^{-6}m^3$

Net volume of pulley;
Solid volume – (volume of groove + volume of shaft hollow)
$9.19 \times 10^{-4} - (3.39 \times 10^{-4} + 9.2 \times 10^{-6})$
$= 2.318 \times 10^{-4}m^3$

Using mild steel, density = $7850kg/m^3$
Mass of pulley = Density × Volume
$= 78.50 \times 2.318 \times 10^{-4}$
= 1.82 kg
Weight of pulley = 1.82 × 9.81 = 17.85N

2.3.4. Power Requirement

The power required to dig the soil (P_d) was obtained from equation 2.15.

$P_d = S_R * d * w * v$ (2.15)

Where,
d = depth of cut, cm
w = effective width of cut, cm
S_R = soil resistance, kg f/cm^2

The total power required was calculated from equation 2.16.

Total Power, $P_t = P_d/\eta$ (2.16)

Where,
P_d = power required to dig the soil
ɳ = efficiency of transmission, %

$$P_d = \frac{1.05 \times 5 \times 50 \times 1}{75}$$

= 3.5hp

$$P_d = \frac{3.5}{0.82}$$

= 4.23 hp

Thus, a prime mover of 5hp was required for this weeder.

2.3.5. Lengths of Tines Design

The cylinder consists of six tines of equal lengths. The lengths (L) of tines were measured and stated as follow:

AB = 30 mm
BC = 30 mm
Length = AB + BC = 30+30 (mm)
= 60mm

2.3.6. Force Analysis

2.3.6.1. Weeding Force

Draft data for tillage implements were reported as the force required in the horizontal directions of travel (ASAE D230, 1986). Only functional draft (soil and crop resistance) was reported. The total implement draft was obtained by adding the rolling resistance (RR) of the transport wheels. The draft per unit effective width at typical field speeds for contemporary cultivator was given by ASAE standards as:

115+230d N/m

Where,
d = tool depth, cm

Taking the average of the two extreme values, draft per meter at 2cm depth (by design) was calculated.

$$[\frac{115+230}{2}] \times 0.02 = 3.45 \text{ N/m}$$

The width of weeding tool was 40cm (by design)

Hence, draft of implement = 3.45 × 0.4
= 1.38N

The rolling resistance (RR) was given as

$$RR = \frac{Clbd}{C_n}[\frac{1.2}{C_n} + 0.04] \quad (2.17)$$

Where,
C_n = dimensionless ratio as a function of the cone index (CI) for the soil
h = unloaded wheel tyre section width
d = unloaded overall wheel tyre diameter

For tilled agricultural drive wheel tyres, bd/w = 0.25 on typical soil surface, CI = 80 C_n = 20

Where,
w = dynamic load in Newton normal to the soil surface and was given as

$$W = \frac{CIbd}{cn} \quad (2.18)$$

For wheels on the weeder, b = 0.0738, d = 0.0355m

Substitute these values into equation (2.17),

$$RR = \frac{80 \times 0.0738 \times 0.0355}{20}\left[\frac{1.2}{20} + 0.4\right] = 1.048 \times 10^{-3}$$

RR for the 3 wheels = 4.19×10^{-3}N
∴ Total draft = $1.38 + 4.19 \times 10^{-3}$ N
= 1.38 N

The force acting during cutting is illustrated in Figure 3 and it is the force F applied at an operating angle α which were resolved into two components, the vertical components Fsin α that causes the penetration of the cutting knife edge and the horizontal components Fcos α that causes the shearing of a thin sheet of soil along with roots of weeds.

For the weeder, $\alpha = 2.3^0$, therefore,
$F\cos 2.3^0 = 1.38N$
F = 1.3811N

The isometric view of the rotary weeder is therefore presented in figures 4–6.

2.4. Performance Evaluation of the Weeder

2.4.1. Field Preparation

The evaluation of the operational effectiveness of the rotary power weeder was carried out at Landmark University's experimental field located behind the Engineering Workshop and at the University's Teaching and Research Farm. The soil classifications in these fields were determined to be sandy loam based on their textural characteristics (Adebayo, 1990). About 5m × 4m plot of land was mapped out and marked on the three different locations to allow for two replicates of fields experiment. Experimental blocks (field plots) were made of spear grasses in field plot 1 and thick long shrubs in field plot 2. The weeding tools were tested on the mapped plots to determine the weeding index and efficiency.

2.4.2. Weeding Index

The weeding index is a measure of the effectiveness of a weeder in removing weeds. It was calculated by comparing the number of weeds removed by the weeder to the total number of weeds initially present in a specific area. The weeding index was expressed in percentage (Rangasamy *et al.,* 1993).

Equation 2.19 was used to calculate the weeding index.

$$\text{Weeding index, } I_w = \frac{W_1 - w_2}{W_1} \quad (2.19)$$

Where,
W_1 = weeds before weeding
W_2 = weeds after weeding

2.4.3. Weeding Efficiency

The weeder was tested on the same field to determine weeding efficiency.

The result was calculated using equation 2.20.

$$\Sigma = \frac{w_1 - w_2}{w_1} x^{100} \quad (2.20)$$

Where,
W_1 = number of weeds before weeding
W_1 = number of weeds after weeding
Σ = weeding efficiency

2.5. Data Analysis

The obtained data was analyzed using Analysis of Variance (ANOVA) and post hoc tests with the help of IBM SPSS. Duncan analysis and LSD were employed as the post hoc test (Erinle *et al.*, 2000). The study employed a 4 × 3 factorial experiment design on the weeding tool and three levels of speed. The experiment also utilized a randomized complete block design with two blocks (field plots) to minimize variability. The objective of the analysis was to investigate the impact of the weeding tool at different speed levels on weed density.

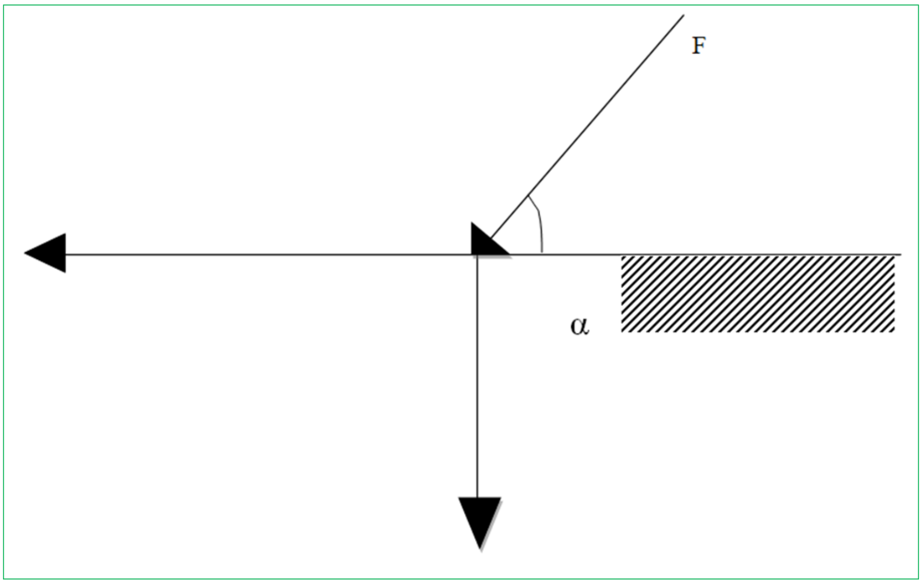


Figure 3. Forces acting during weeding.

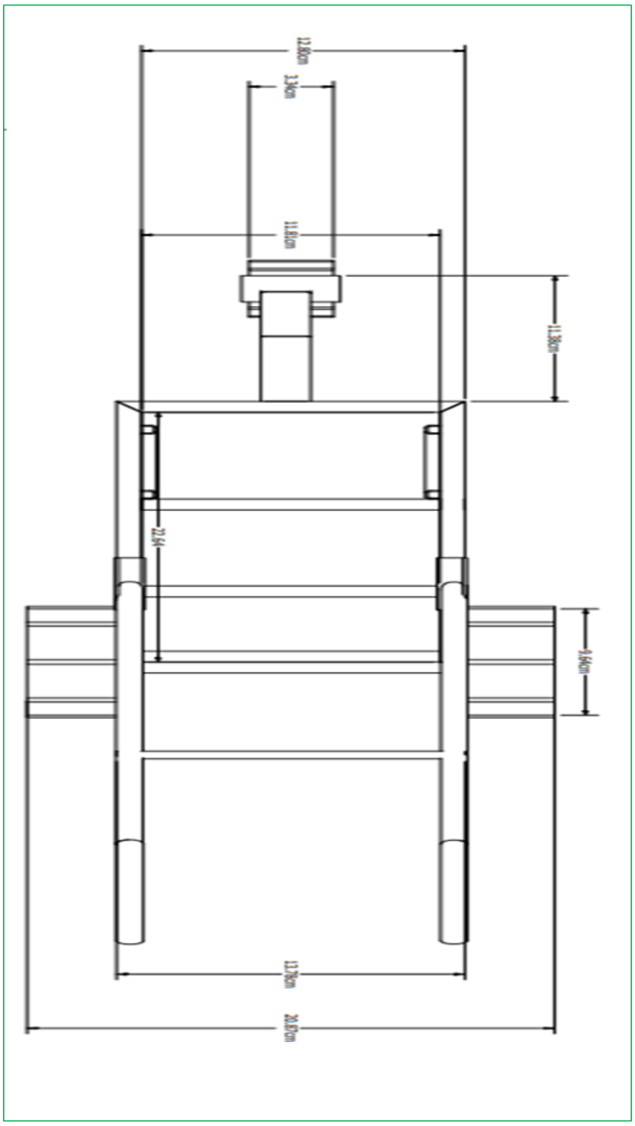


Figure 4. Plan view of the weeder.

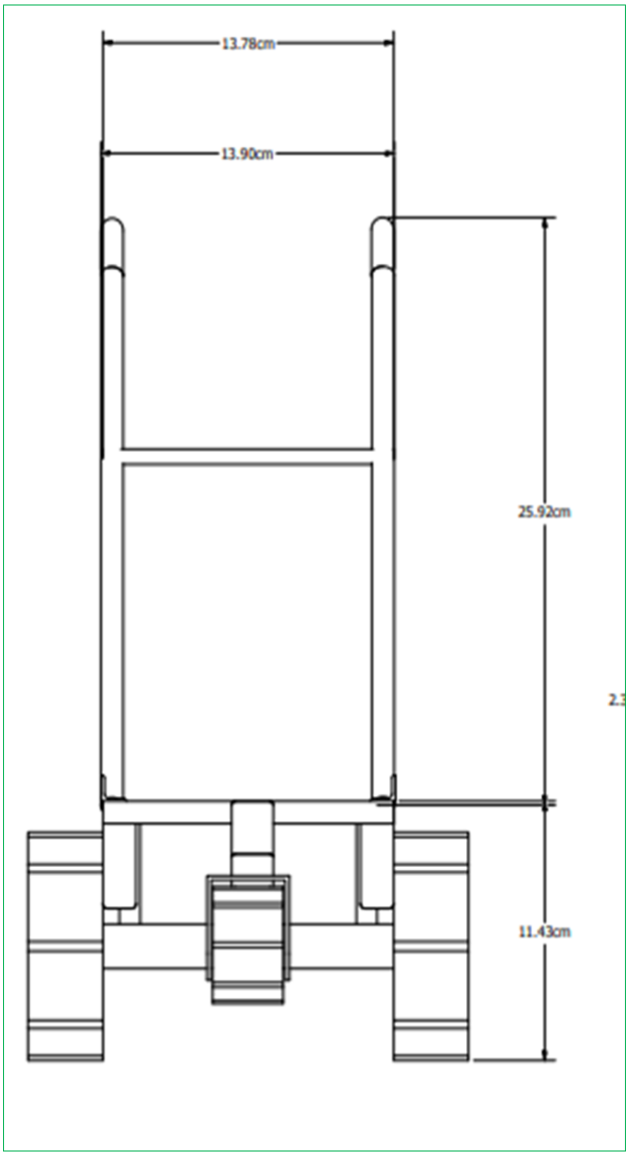


Figure 5. Front view of the weeder.

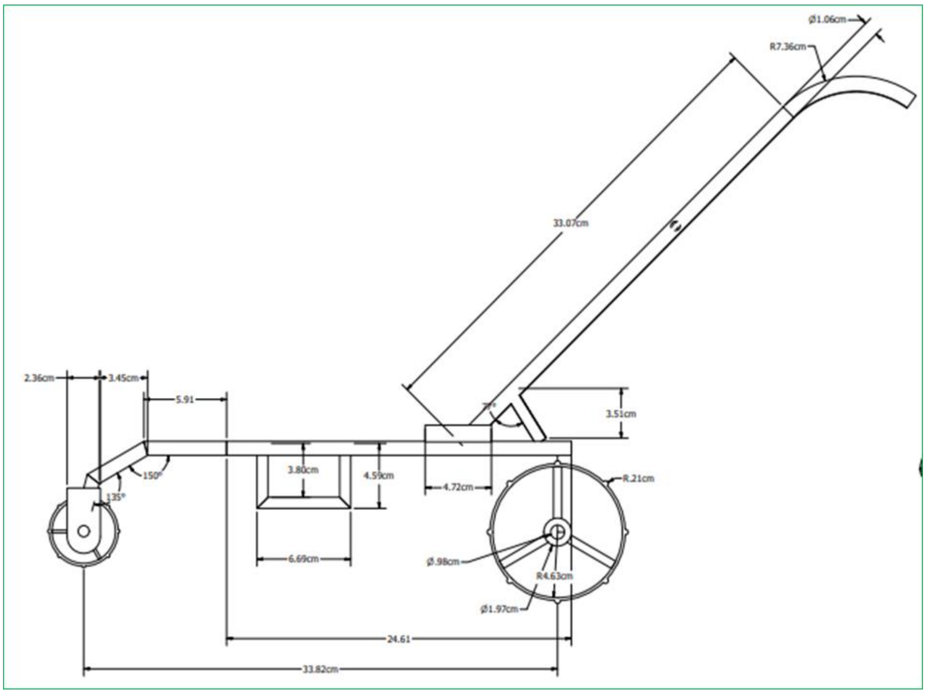


Figure 6. Side view of the weeder.

3. Results and Discussion

Analysis of results as presented in plotted graphs (Figure 7 and 8) revealed that on both field plots at machine speed of 5219 rpm the weeder had the highest weeding efficiency and lowest at speed 1644 rpm. Weeding index on field plot 1 was highest at machine speed 1644 rpm and lowest at 4509 rpm. On field plot 2, the machine speed was highest at 4509 rpm and lowest at 5219 rpm.

Table 1. Speed and weed density on field plots.

Weeding tool	Field plots	Speed (rpm)	Weed density		
			Before weeding	After weeding	Number of weeds removed
Tines	1	1644	769.15	397.24	371.91
	1	4509	659.56	321.32	338.24
	1	5219	596.45	239.65	356.80
	2	1644	731.93	368.15	363.78
	2	4509	614.28	205.69	408.59
	2	5219	534.98	175.96	359.02

Table 2. Weeding efficiency (%).

Field plots	Speed	Weeding efficiency (%)
1	1644	48.35
	4509	51.28
	5219	59.82
2	1644	49.70
	4509	66.51
	5219	66.54

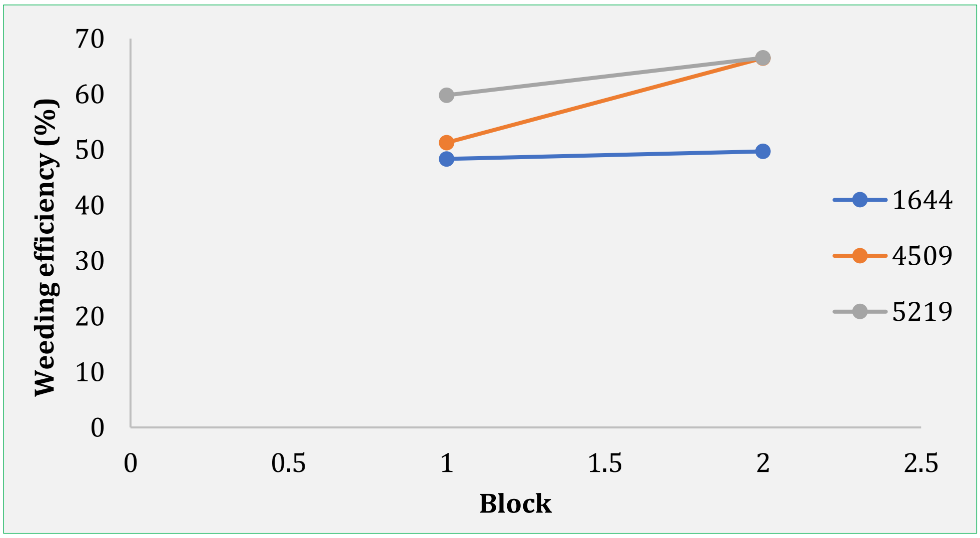


Figure 7. Weeding efficiency against the field plots.

Table 3. Weeding index.

Field plots	Speed	Weeding index
1	1644	371.91
	4509	338.29
	5219	356.80
2	1644	363.78
	4509	408.59
	5219	359.02

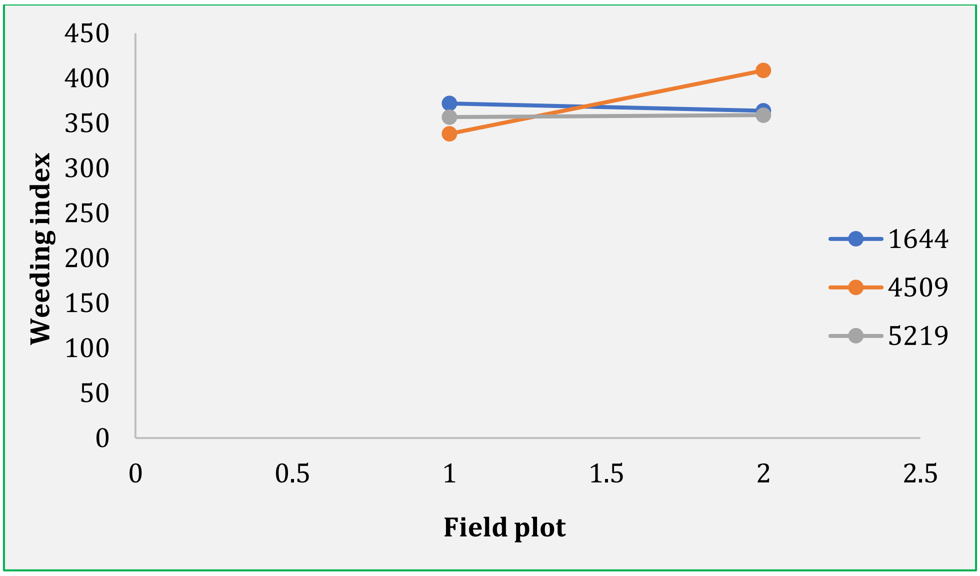


Figure 8. Weeding index against the field plot.

4. Conclusion

A rotary weeder was developed to reduce the drudgery attached with weed control operations. The weeder was evaluated and from the results obtained the following conclusions were drawn when operating the machine on different field plots 1 and 2 with varying speeds. The weeding efficiency of the rotary weeder was at maximum 66.54% on field plot 2 at speed 5219 rpm and minimum 48.35% on field plot 1 at 1644 rpm. Although the goal of the study was partially achieved (66.54%), nevertheless it showed a number of drawbacks that future studies should be aware of through the encountered quandaries that the research process has shown.

Declarations

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Author Contributions: OIM: Supervised the experiment, manuscript-review and editing; AOT, OAA: Manuscript review and editing; EAP: Conceived, conducted and analyzed the experiment, interpreted the data, manuscript review and editing; ASA: Conducted the experiment; OCO, OOR: Manuscript-review and editing.

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