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Development and Evaluation of Wheeled Long-Handle Weeder

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Abstract: *A push-type operated wheel weeder with an adjustable long handle, was designed, constructed and tested. The hoe performance from the tests on a field of Okra plant having an inter-row spacing of 800mm, showed that it could weed satisfactorily, and eliminate the drudgeries associated with the use of the short handle hoe such as backache, pains at the spine and lower waist region. Field capacity and efficiency of 0.050ha/hr and 87.5% were obtained respectively. Furthermore, the average weeding index and performance index obtained were 86.5% and 1108.48, respectively. At a speed of 0.04m/s, a high efficiency of 91.7% at 0.4m depth of cut was obtained. The developed wheeled long- handle weeder was found efficient.*

Keywords: *Push-type, adjustable long handle weeder, weeding index, performance index*

1. Introduction

Weeding is an important but equally labour intensive agricultural unit operation. Weeding accounts for about 25% of the total labour requirement ranging from 900-1200 man hour/hectare during cultivation season (Nag and Dutta, 1979). Its delay and negligence reduces crop yield from 30 to 60% (Singh, 1988). Weed control has become a highly specialised activity employing thousands of people especially in developing countries. This activity involves industries providing the necessary chemicals (herbicide), and individuals engaging in the practices of weed control.

Many weeding implements have been developed, amongst which are the traditional hoes, spades and the cutlasses. Their effectiveness is still very low with high energy demand. The average energy demand of the traditional tillage hoe ranges from 7 to 9.5kJ/min when compared with 4.5 kJ/min (75 watts) which is optimum limit of continuous energy output of man (Nwuba, 1981).

2. Literature Review

Kamal and Babatunde (1999) developed a push type Oscillatory power weeder with the following operational parameters; weeding efficiency, field capacity, depth and width of cut, amplitude and frequency of vibration. Field capacity was found to be 0.036 ha/hr and efficiency 81.34%. Jadhav and Turbatmath (1991) developed a bullock drawn multipurpose hoe. This was designed to suit any row spacing between 300mm and 450mm for inter- cultural operation. The actual field capacity of a pair of the hoe varied from 0.15-0.25ha/hr.

A ridge profile weeder was developed by Odigboh and Ahmed (1980). The weeder consists of two bicycle wheels welded together to a common hub, with the bicycles spokes replaced with 6mm diameter mild steel rods, rear and front sprockets, roller chains, shaft, two gangs of rotary hoe weeders and handle.

Yadav and Pund (2007) developed a wheeled hoe based on ergonomic factors. The performance of the developed weeder was evaluated in the field of groundnut crop. The field capacity of the weeder was found to be 0.048ha/hr. It was observed that the cutting width was proportional to the field capacity. Further evaluation revealed that, the weeding efficiency was 92.5%. The performance index was found to be 2611.7. It was observed that the developed weeder was not only suitable for groundnut crop but could also be used for other crops by adjusting the row spacing.

The use of the common short handle weeding hoe involves the application of much force with little output, the operator experiences backache, pains in the spine and lower waist, as a result of the working posture (Singh, 1992). Singh (1992) developed a wheeled hoe weeder with ergonomic considerations to improve its design and for commercialisation through small scale manufacturers. It required 60-110 man-hr/ha for weeding in black heavy soil and 25 man-hr/ha in light soil.

The usage of the wheel long handle weeding hoe has not been widely accepted by majority of the local farmers. In some countries e.g. Nigeria, most people often seen standing while working in the farm are regarded as been lazy. As a result of this misconception, the use of the wheeled long-handle weeding hoe has not been fully accepted.

Rangasamy et al. (1993) and Kamal and Babatunde (1999) reported that when a manually operated weeder, having a field capacity greater than the traditional hoe, was tested on a small plot of land with crops planted in rows, the machine had a low output of about 0.02ha/hr because of a lot of rigour involved in its usage. Farmers also experience a lot of rigour when using short handle hoes such as backaches or strains and spine problems at old age. Improving effectiveness in agricultural mechanization and ease in drudgeries associated with the use of short handle hoe, has initiated the design of wheeled long-handle hoe.

The designing and development of a wheeled long handle weeding hoe (WLHWH) was conceived by the desire to eliminate the drudgeries and remedy the difficulties associated with short handle hoe and save the peasant farmers the stress of bending while working, for effectiveness in agricultural mechanization. Thus, the objectives of this study are to design and fabricate a wheeled long-handle weeding hoe, test and analyse its performance on field capacity and efficiency, and compare its performance with that of short handle weeding hoe.

3. Material and Methods

The weeder was designed based on the principle of weed stem failure due to soil shearing, impact and abrasion. The material selection was considered in terms of cost, availability, durability, overall weight and affordability. The design parameters considered were the ease of operation, average walking speed of the operator (0.8m/s), energy requirement of the weeder, and types of weeds to be operated upon. The material used for the shaft was mild steel. The shaft was designed based on strength, rigidity and stiffness. The shear stress, bending moment and deflections were also considered.

The push-type long handle weeder is shown in isometric view, plan view and rear view as in Figures 1, 2 and 3, respectively.

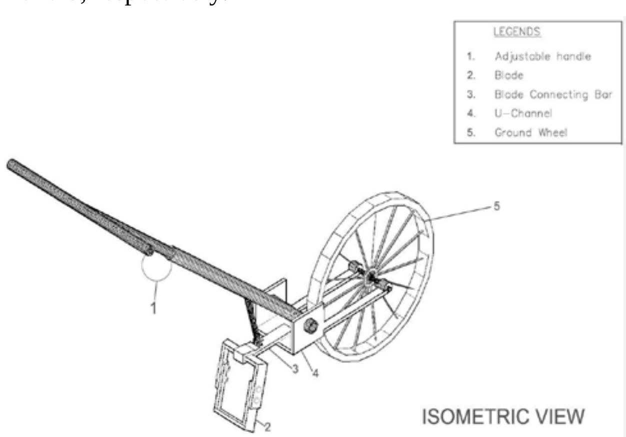

Figure 1. Isometric view of the weeder

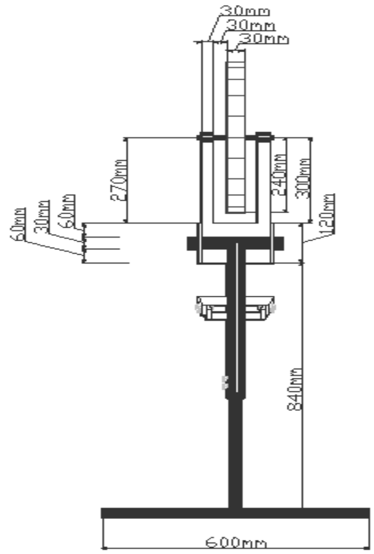

Figure 2. Plan view of the weeder

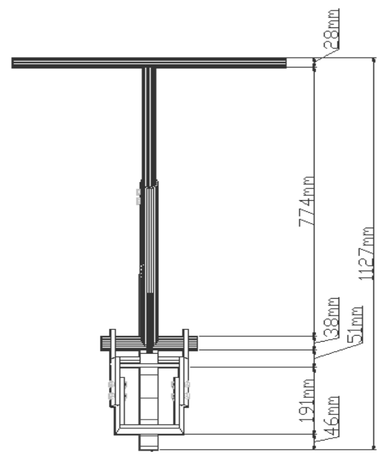

Figure 3. Rear view of the weeder.

The main components of the machine and their functions are as follows:

1) The Handle - This was constructed with two galvanized pipes of lengths 900mm and 471mm respectively, making a total length of 1371mm. The galvanized pipes were welded across the mainframe handle to form the hand grip which has a length of 140mm. The handle enables the operator to push or pull and direct the machine during operation within the crop rows. It also enables the operator to raise the cutting blade a little bit high, should stone and stumps be encountered during operation. The handle is made adjustable to create comfort to the operator irrespective of the operator's height. The essence of the long handle is to enable an upright posture while on weeding operation.

2) Weeding blade - The weeding blade was made from 51mm × 210mm mild steel having a thickness of

14mm. The blade at the lower end was sharpened and slanted to an angle of 15° to the horizontal. It is attached to a headpiece by means of bolt for easy replacement due to wear and tear. The blade has a maximum cutting depth of 0.6m with design width of cut of 0.2m.

3) Ground wheel - The ground wheel has a diameter of 300mm and a hub of 25mm made from mild steel. The hub was attached to the centre of the wheel with the aid of spokes. The essence of the wheel is to enable easy movement while the implement is in use.

4) U-channel - The U-channel is made of a steel plate of 1.5mm thick with dimension 124mm × 120mm × 51mm. The U-channel creates a fulcrum base for the ground wheel, blade, handle and the connecting flat bar linking the hub to the U-channel.

5) Blade connecting bar - This is made of steel flat bar 250mm×51mm. It acts as linkage from the blade head piece to the U-channel with the aid of bolt and nut.

6) Ground wheel connecting bar - This is made of a flat bar 295mm × 24mm. It connects the ground wheel from the hub to the U-channel. The ground wheel connecting bar is a two-piece flat bar.

7) Blade headpiece - This unit consists of mild steel with dimensions 170mm x 125mm. The blade is connected to the blade headpiece by means of bolt and nut. It is curved to almost a semi U-shape.

4. Design Theory

4.1 Shaft Design

The design of the shaft for the rigidity was based on the shaft diameter, the maximum impact force by the operator and soil resistance force. The detailed calculation for obtaining maximum load that the shaft would be subjected to during operation is presented in equation 1 (Khurmi and Gupta, 2005).

$$d = \sqrt[3]{\frac{32BM\max}{\pi\tau}} \quad \text{. .... (1)}$$

where

d = diameter of the shaft (m)

BM = bending moment (Nm)

τ = the allowable shear stress, 99999N/m^2,

4.2. Finite Element Method

The first step in the *Galerkin* Finite Element Method is the discretization of the domain. Here, the domain of the problem (length of the beam) is divided into a finite set of line elements, each of which has at least two end nodes. The second step is to obtain the weak form of the differential equation. Therefore, the corresponding system can be represented as equation 2 (Rao et al., 2012).

$$\frac{EL}{L^3}\begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ 12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{bmatrix} = \frac{LP}{2}\begin{bmatrix} 1 \\ 6L \\ 1 \\ -6L \end{bmatrix} \quad \text{.........(2)}$$

[Stiffness matrix][Displacement matrix] = force vector.

The system of equations is solved using MATLAB. Results were found for various numbers of elements under different loads. The computer program used for calculating the shear force, bending moment, slope and deflection diagrams for the design of the push-type adjustable long-handle weeder is presented in Appendix I.

4.3 Design for U-Base Channel

Figure 4 shows the U-channel base. The U-base channel is carrying load along section (x-x), therefore equation 3 (Khurmi and Gupta, 2005) shows the section modulus.

$$Z_{XX} \geq \frac{2I_{XX}\left(aH + bt\right)}{aH^2 + bt} \quad \text{...(3)}$$

$$I_{XX} = \frac{Bh^3 - b(h-t)^5 + ah^3}{B} \quad \text{...(4)}$$

Equation 4 is the moment of inertia at (x-x).

where

a = area of the section

H = height of the U- channel

h = height of the inner U-channel

b = width of the inner U- channel

t = thickness of the U- channel

B = width of the outer U – channel

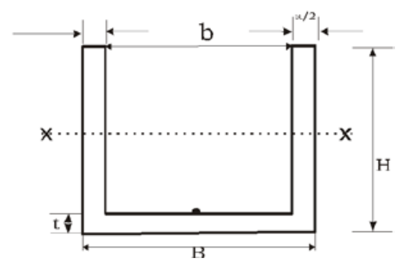

Figure 4. U- channel base

4.4 Design of Cutting Blade

Figure 5 shows the cutting blade. The draft force (D) is the resultant of the normal loading of the soil on the metal and component parallel to the blade.

$$D^2 = V^2 + W^2$$

$$D = \sqrt{V^2 + W^2}, \ (N) \quad \text{.............................(5)}$$

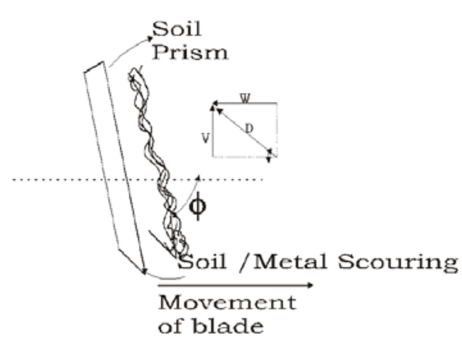

Figure 5. Cutting blade

When soil-acting mechanical weeder-control implements are used, the soil is subjected to cutting or shear force which cause it to fail. Also the movement of the soil acting elements of a weeder through the soil is affected by: adhesion of the soil /material, friction between soil and metal (cutting blade) described by the angle of soil/metal friction.

The relation between the resistance to soil sliding over the metal (cutting blade) surface is given by equation 6 (Hendrick and Bailey,1982) as

Hmax = CA + W tan ……………......................(6)

where

Hmax = the maximum soil/metal sliding force
A=Area of metal in contact with the soil.
W = normal loading of the soil on the metal
Tan = adhesion of the soil material interface
Angle of inclination of the blade (angle of attack)

The blade has to be inclined at a suitable angle so as to allow easy penetration into the soil and to avoid excessive tilling of the soil. Angle of attack ϕ of approximately 15^0 is ideal to lift and separate the weeds from the soil. The draught force of weeder can be calculated from equation 7 (Yadav and Pund 2007)

$$D = W\, x\, dw\, x\, R_S \quad \text{..(7)}$$

where

D = Draft force of the weeder (N)
dw = Depth of cut (m)
W = Width of cut (m)
Rs = Soil resistance (N/m^2)

4.5 The Power Requirement

Power required to move weeder and weed the grasses is calculated from equation 8 (Yadav and Pund 2007)

$$P = \frac{D\, x\, S}{75}(hp) \quad \text{..(8)}$$

where

D = Draft force of the weeder, N
S= Travelling speed (m/s)

4.6 Design of the Handle

Figure 6 shows the handle. The handle is made of a cylindrical steel pipe of diameter 20mm.

$$F_3 = F_1 + F_2$$

$$F_1 = \frac{F_2 \times b}{a}$$

$$F_3 = \frac{F_2 \times b}{a} + F_2 \quad \text{……………………………….(9)}$$

It is subjected to bending forces and is determined by equation 10 (Hall et al., 1980).

$$\delta_h = \frac{m_h Y_h}{R_w} \quad \text{...(10)}$$

where

δ_h = bending stress on handle,
m_h = moment in handle,
Y_h = distance from neutral axis,
R_w = second moment of area

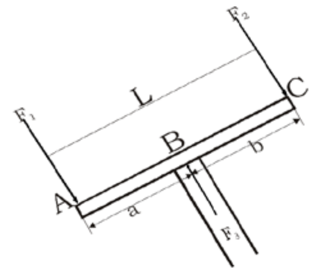

Figure 6. The handle

5. Experimental field layout and Performance Test

A field test was conducted to evaluate the performance of the developed weeder in terms of field capacity, weeding index, plant damage, performance index, field efficiency and effective field capacity and the weeding efficiency for comparison with the short handle hoe and others.

The test was conducted in a field of Okra plant having an inter-row spacing of 800mm with an area of 6m by 2m. The field area of 12m^2 was divided into four plots of 2m by 1m wide with a space of 0.5m between each of the plots. Each of the plots was further subdivided into four blocks of 2m by 800mm. The blocks were denoted as block 1, block 2, block 3 and block 4, respectively. The weeding operations in four of the blocks were randomly carried out. These were conducted in four replicates and average readings were taken. Before and after the weeding operations, numbers of grasses with average plant height of 610mm and grasses which varied between 70mm-200mm were randomly counted and recorded. With the aid of a stop watch, times taken for weeding each of the blocks for instance, block 1, block 2, etc. were recorded, excluding the turning times of the weeder. Altogether there were sixteen (16) treatments. The forward speeds of the operator were computed respectively. The depths and widths of cut were measured using a steel rule. The number of weeds per area before and after weeding operations were counted and recorded. The number of the damaged plants were counted and recorded and the required draught force was determined.

In the test, anthropometric and ergonomic data were collected from 10 randomly selected farmers, males and females of age group between 20 to 50 years. The weeding operations were carried out by each of the participating farmers. The sequence of weeding operations was done until the area of the field was completed. The ergonomic parameters analysed were based on human body measurement which includes body weight, standing height, arm reach, palm length and functional leg height, which were all measured. At the end of the weeding operations, each of the operators gave information concerning ergonomic rating within the range 0 to 10 i.e. uncomfortable to very comfortable rating, after which statistical modelling was employed.

Proper ergonomic design is very necessary for the construction of this implement for ultimate comfortability, convenience and safety of the operators. Soil texture of the experimental field was determined using sieve analysis. The soil was found to be sandy-loam, with average moisture content of 12%.

5.1 Weeding Index

Weeding index can be calculated using the following equation 11 (Yadav and Pund, 2007).

$$Weeding\,index\,(\%) = \frac{W_1 - W_2}{W_1}\,x\,100 \quad \text{........................(11)}$$

where

W_1 = number of weeds per area before weeding

W_2 = number of weeds per area after weeding

5.2 Plant Damage

Plant damage percentage is measured using the following equation 12 (Yadav and Pund, 2007).

$$Q = \left[1 - \left(\frac{q}{p}\right)\right] x100 \quad \text{...(12)}$$

where

Q = plant damage

q = number of plant in a 6m row length after weeding

P = number of plant in a 6m row length before weeding

Thus, DP = P – Q the number of plant damaged (DP)

5.3 Performance Index

The weeder performance was accessed through performance index (PI) by using equation13 (Yadav and Pund, 2007)

$$PI = \frac{aqe}{F} \quad \text{...(13)}$$

where

a = field capacity of weeder (ha/hr)

q = plant damage (%)

e = weeding index (%)

F = required draught force

5.4 Field Capacity and Efficiency

Theoretical field capacity

(FC_t) = S x W, ha / hr ....(14)

where

S = forward speed of weeder, m/s^2

W = width of the implement, m

Effective field capacity

$$(FC_e) = \frac{land}{time}\frac{ha}{hr}$$

$$\text{Field efficiency} = \frac{FC_e}{FC_t} x100\% \quad \text{..............................(15)}$$

where

FC_e = Effective field capacity

FC_t = Theoretical capacity

6. Results and Discussions

The performance data of the weeder is presented in Table 1, while in Table 2, showed the comparison of field performance of the wheeled long and short handle hoes.

Table 1. The performance parameters of the wheeled long- handle hoe

S/no	Description	Parameters
1	Width of cut	0.45m
2	Depth of cut	0.4m
3	Weeding index	86.5%
4	Field capacity	0.050ha/hr
5	Weeding efficiency	91.7%
6	Weight	5.3 kg
7	Performance index	1108.48
8	Plant damage percentage	8%

Table 2. Comparison of field performance of the wheeled long-handle and Short handle hoes

Implements	Moisture Content (%)	Actual Field Capacity (ha/hr)	Weeding Index (%)	Plant Damage (%)	Performance Index
Wheeled long-handle hoe	13.09 10.05	0.050 0.045	86.6 84.4	8 10	1108.48 1899.0
Short handle hoe	13.09 10.05	0.028 0.014	83.3 84.4	7 12.5	901.2 1342.7

It is indicated in Table 2 that as moisture content decreased, there was also a decrease in actual field capacity. For example, at the moisture content of 13.09%, the actual field capacities were 0.050 and 0.08ha/hr for long-handle hoe and short handle hoe while at moisture content of 10.05%, the actual field capacities were 0.045 and 0,014 ha/hr respectively. This might be due to stickiness of soil which causes clogging of soil weed mass in weeding element. The weeding index was found to be in the range of 83.30 to 86.6% at different moisture contents. The developed wheeled long hoe has a maximum weeding index of 86.6% and a minimum value of 84.4% while short handle hoe had 84.4% and 83.3%. This could be as a result of differences in the soil moisture contents.

The highest plant damages of 10% and 12.5% at 10.05 moisture content were obtained from wheeled and short handle hoes respectively. There is every tendency for an increase in the number of plant damaged at moisture content below 10.05%. This is so because with decrease in moisture content soil hardness is increased, hence causing difficulties in penetration of weeding blade to desired depth, and sometimes skid over and strike the plant. A higher percentage of plant damage at 13.09% moisture content of the short handle hoe can be attributed to carelessness of the farmer. The highest performance index of 1899.0 and 1342.7 were obtained respectively at 10.05% moisture content, while the lowest value of 1108.48 and 901.2 were obtained at 13.09% moisture content. The decrease in the performance index may be due to lower field capacity and higher plant damage.

It is shown in Table 3 that the existing developed machines by some researchers and their field performance. These weeders were engine powered. For instance, the engine-powered, manually operated roto-weeder employing the principle of a rotary tiller was powered by a 1.45hp petrol engine (Nkakini et al., 2009). Engine-powered rotary weeder for wet land paddy was developed by Viren and Ajav (2003), but had difficulties of manoeuvrability and was not easily affordable by peasant farmers. The Push-type Oscillatory power weeder was also engine powered (Kamal and Babatunde, 1999). They all ended up in introducing gasses such as carbon monoxide into the environment, because they were engine powered. The wheeled long-handle weeder is friendly to the environment, since it does not emit carbon monoxide into the environment. It is also simple and affordable by peasant farmers for small-scale farm mechanization.

Table 3. Field performance Comparison of other similar existing weeders

Implements (Weeders)	Field capacity (ha/hr)	Weeding efficiency (%)	Width of cut(m)	Depth of cut(m)
Wheeled long-handle weeder	0.050 ha/hr	91.7%	0.45m	0.4m
Traditional Short handle hoe	0.028 ha/hr	87.5%	0.35m	0.6m
Engine-powered, manually operated roto-weeder	0.037 ha/hr	90%	0.35m	0.3m
Push type Oscillatory power weeder	0.036 ha/hr	81.34%	0.36m	0.4m
Wheeled hoe based on ergonomic factors	0.048 ha/hr	92.5%	0.45m	0.5m

The weeder is used for weeding operation along the inter-row spaces of crops and weeding operations are done in an upright position, resulting in the reduction of backache, pains in the spine and waist pain by the operator. Thus, it is different from the traditional short handle hoe (Singh, 1992). Furthermore, this weeder also has other advantages such as reduction of labour, time and drudgery when compared with traditional weeders. This weeder performs well in flat dried soil. Table 4 presents material bill for construction of wheeled long-handle weeder.

Table 4. Material bill

S/No.	Descriptions	Materials	Quantity
1	Round pipe	Galvanised pipe	2.44m long
2	U- Channel	Steel plate of mild steel iron	1
3	Bolts and nuts	Mild steel	18
4	Flat bar	Mild steel iron	0.609m
5	Shaft	Round iron of mild steel	1
6	Ground wheel	Rubber and mild steel iron	1
7	Tyre	Rubber	1
8	Hub	Mild steel	1

The effect of width of cut on efficiency of the machine is shown in Figure 5. The result indicates that from 0.2m to 0.3m width of cut, the efficiency increased to 93.5%. The highest efficiency of 95% was attained at 0.4m width of cut.

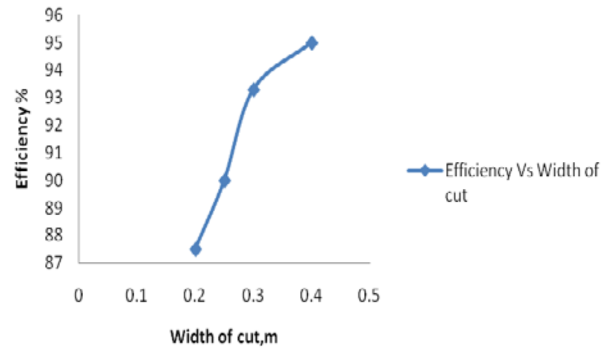

Figure 5. Effect of width of cut on efficiency

The effect of speed on efficiency of the weeder is shown in Figure 6. The weeding efficiency linearly increased from 90% to 91.7% within the speeds of 0.02m/s to 0.04m/s. The weeding speed of 0.04m/s recorded the maximum efficiency of 91.7% which sharply dropped to efficiency of 90% at 0.06m/s. It then remained constant from 0.06m/s to 0.8m/s at weeding efficiency of 90%. This indicates that the best weeding speed for push-type wheeled long-handle weeder is 0.04m/s.

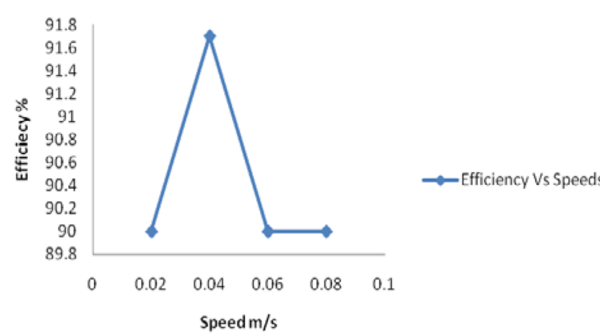

Figure 6. Effect of speed on efficiency

Figure 7 shows the effect of angle of cut on efficiency. The trend shows a non-linear relationship between the angle of cut and efficiency. It is obvious that at 15° angle of cut, the highest efficiency of 90% was obtained, while the lowest efficiency of 60% was obtained at 20° angle of cut. The best angle of cut is 15° and followed by 30°.

7. Conclusion

A wheeled push-type long- handle weeder was designed, fabricated and tested. The weeder performed

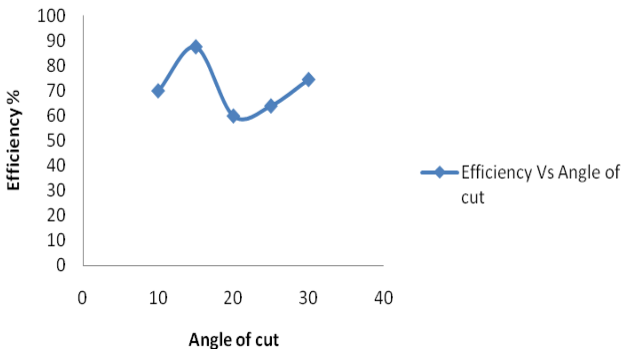

Figure 7. Effect of angle of cut on efficiency

satisfactorily with a weeding efficiency of 91.7%, weeding index of 86.5% and performance index of 1108.48. A field capacity of 0.050 ha/hr at width of cut of 0.45m and depth of cut of 0.4m was obtained. The comparison of field performance of the weeders showed that the performance index of short handle is a bit higher than wheeled long- handle weeder at 13.09% moisture content. The wheeled push-type long-handle weeder is user friendly and easy to maintain. It is however not common in the commercial market because of lack of awareness and the fact that it is more expensive than the short handle hoe.

On the whole, it is a better option because of the standing position of the operator which eliminates backache, pains at the spine and lower waist region of the operator, reduction in time spent in operation and the energy/force applied. This wheel-long handle hoe consists of a wheel, a weeding blade, U-channel and an adjustable long handle to enable the operator to use it even at an erect/standing position giving it a better edge over the short handle hoe.

Appendix I:

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% A COMPUTER PROGRAM TO SOLVE AND PLOT THE
SHEAR FORCE AND...
%BENDING MOMENT DIAGRAMS FOR THE DESIGN OF A
MANUALLY OPERATED WEEDER
Wth=1.%Width of Cut
dth=.4%Depth of Cut
Rs=80e3%Soil Resistance Force
Df=Wth*dth*Rs%Draft Force
F3=Df
F1=-F3/2
F2=-F3/2
Ft=[F1 F1 F3 F3 F3 F2 F2]'%Shear Force
x=[0 1 1 2 3 3 4]'%Length of Shaft
BM=Ft.*x%Bending Moment
subplot(2,1,1)
plot(x,Ft,'--*')
xlabel('Length of Shaft(m)')
ylabel('Shear Force(N)')
title('Shear Force Diagram')
grid on
subplot(2,1,2)
plot(x,BM,'--*')
xlabel('Length of Shaft(m)')
ylabel('Bending Moment(Nm)')
title('Bending Moment Diagram')
grid on
gtext('BMmax')
```

x(cm)	SF(N)	BM(Ncm)
0	-16000	0
1	-16000	-16000
1	32000	32000
2	32000	64000
3	32000	96000
3	-16000	-48000
4	-16000	-64000

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