Design and Development of Ridge Profile Power Weeder

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4 authors, including:

Deepak S Thorat
Indian Council of Agricultural Research

P.K. Sahoo
Indian Agricultural Research Institute

Mir Asif Iquebal
Indian Agricultural Statistics Research Institute

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Design and Development of Ridge Profile Power Weeder

Thorat Deepak Sabaji[1], P. K. Sahoo[2], Dipankar De[3] and Mir Asif Iquebal[4]

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ABSTRACT

Improper weed control methods can cause about 30–35% reduction in crop yield. Mechanical weed control on ridges is still a major problem. A ridge profile power weeder was designed and developed for weeding of ridge planted crops. The main working components of the weeder were cutting blades and rotor shaft. Three types of blades (L-type, C-type and Flat-type) were selected having length, width and thickness of 100 mm, 25 mm and 6 mm, respectively, operating with a rotor shaft of 18 mm in diameter. C-type blades were most suitable at gang speed of 200 rpm and 15.26±0.96% (d.b) soil moisture content with weeding efficiency, plant damage, field capacity of 91.37%, 2.66%, and 0.086 ha.h^{-1}, respectively. Time saving with ridge profile power weeder as compared to manual weeding was 92.97 per cent.

Key words: *Ridge profile, mechanical weeding, weeding efficiency, plant damage*

Weeds are one of the major biotic constraints in agricultural production. As per available estimates, weeds cause up to one-third of the total losses in yield, besides impairing produce quality and raising cost of production (NRCWS, 2007). The present weed control practices in India are chemical, mechanical and biological. Manual weeding, besides being laborious, is inefficient (not done on time in most cases), and always not practical because of adverse soil conditions. Mechanical weed control is preferred among all weeding methods due to many reasons. A study undertaken at DWSR suggests that proper weed management technologies, if adopted, can result in an additional national income of Rs.1,05,036 crores per annum (NRCWS, 2007).

Zareiforoush *et al.* (2010) presented a new theoretical approach to design main tillage components of rotary tillers. In designing the rotary tiller shaft, it was revealed that in addition to the torsional moment, the flexural moment was also effective on the system safety. It was also recognized that in designing a rotary tiller, blades are most subjected to fracture by incoming stresses. The optimal value of rotor diameter considering the values of maximum tangent force was about 39.4 mm.

Niyamapa and Chertkiattipol (2010) designed three prototype rotary blades to reduce the tilling torque, impact force and specific tilling energy, and tested in a laboratory soil bin with flat tilling surface. Experiments with the prototype rotary blades and Japanese C-shaped blade were carried out at forward speeds of 0.069 and 0.142 m.s^{-1} and at rotational speeds of 150, 218, 278 and 348 rpm (or 3.30, 4.79, 6.11 and 7.65 m.s^{-1}) by down-cut process in clay soil. Also, tests with European L-shaped blade and European C-shaped blade at 0.069 m.s^{-1} forward speed at same rotational speeds were conducted. Experimental results of the prototype rotary blades indicated that their torque was evidently less than that of Japanese C-shaped blade. Specific tilling energy per tillage round for new blades was less than that of Japanese C-shaped and European C-shaped blades. Padole (2007) evaluated rotary power weeder for its field performance in comparison with bullock drawn blade hoe. It worked better than bullock drawn blade in respect of working depth of 56.7 mm (16.67% higher), effective field capacity of 0.14 ha.h^{-1} (40% higher) and field efficiency of 90% (34.11% higher) than that of bullock drawn blade hoe. A weeding machine consisting of four-bar mechanism in which blade was placed on coupler link was evaluated by Akhijahani *et al.*(2011). Experiments were carried out at vehicle speeds of 1.27, 2.1, 3.5 and 5.4 km.h^{-1} and rotational speeds of 70, 93, 134 and 184 rpm in corn field.The optimal forward speed and rotational speed were 5.4 km.h^{-1}and 134 rpm, respectively.

Presently, no ridge profile power weeder is being used commercially in abroad or India for ridge planted crops. Therefore, a study was undertaken to develop a ridge profile power weeder for small and medium land holdings.

MATERIALS AND METHODS

A manually operated ridge profile power weeder was designed for weeding of ridge planted potato crop. From design point of view, the rotor shaft and cutting blades were the two important components of the ridge profile power weeder.

[1] *M.Tech.Scholar, Division of Agricultural Engineering, IARI, New Delhi,* [2,3] *Principal Scientist, Division of Agricultural Engineering, IARI, New Delhi,* [4] *Scientist, IASRI, New Delhi. Corresponding author e-mail:* sahoopk_1965@rediffmail.com

Power Requirement

Soil resistance has a considerable effect upon the power requirement of weeder. Also, width of cut and speed of operation influences power requirement of weeder. For calculating draft of the weeder, specific draft of soil was taken as 25 N.cm^{-2} (for sandy loam soil). The speed of operation of the weeder was considered as 1 to 1.2 km.h^{-1}. Total width of coverage of cutting blades was 400 mm as single ridge having 200 mm one side slanting length. The depth of operation was considered as 40 mm as at weeding stage depth of root of weed was not more than 40 mm (after 25 days of planting of potato crop). Based on the above assumptions, draft was estimated to be 4000 N.

Considering belt-pulley power transmission efficiency of 70%, corresponding power requirement was calculated as:

Total power requirement (kW),

= (Draft, N X Speed, m.s^{-1}) / (Efficiency, %) . . . . .(1)

= (4000 X 1.2 X 1000) / (3600 X (70/100))

= 1.90 kW

Therefore, an engine of 2.20 kW was selected as a power source for the weeder.

Design of Rotor Shaft

Minimum revolutions required for weeding was assumed to be 150 rpm at soil moisture content 11.3% (db) (Niyamapa and Chertkiattipol, 2010). For designing the rotor shaft, the maximum tangential force which can be endured by it was considered. The maximum tangential force occurs at the minimum tangential speed of rotor shaft, which was calculated by the following equation (Bernacki *et al*., 1972):

$$K_s = C_s \frac{75\, N_c M_{cM_z}}{u_{min}} \qquad \ldots(2)$$

Where,

K_s = Maximum tangential force, kg,

C_s = Reliability factor (1.5 for non-rocky soils and 2 for rocky soils),

N_c = Power of engine, hp,

η_c = Traction efficiency for the forward rotation of rotor shaft as 0.9,

η_z = Coefficient of reservation of engine power (0.7-0.8), and

u_{min} = Minimum tangential speed of blades, m.s^{-1}.

Tangential peripheral speed, u_{min}, can be calculated using the following equation:

$$u_{min} = \frac{2\,\pi\, N\, R}{6000} \qquad \ldots(3)$$

Where,

N = Revolution of rotor, rpm, and

R = Radius of rotor, cm.

After substituting values for revolution of rotor shaft (150 rpm) and its radius as 50 mm in equation (3), tangential peripheral speed was obtained as 0.785 m.s^{-1}. Using the tangential peripheral speed and other parameters in equation (2), the maximum tangential force was determined to be 290.2 kg.

With rotor shaft radius of 50mm, moment acting on it was 1451 kg.cm.

The yield stress of rotor made from rolled steel (AISI 302) was 520 MPa. The allowable stress on the rotor (τ_{all}) was calculated by the following equation (Mott, 1985):

$$\tau_{all} = \frac{0.577\, k\, \sigma_y}{f}$$

$$= \frac{0.577 \times 0.75 \times 520}{1.5}$$

$$= 150 \text{ MPa} = 1530.6 \text{ kg.cm}^{-2} \qquad \ldots(4)$$

Where,

Tall = Allowable stress on rotor shaft, kg.cm^{-2},

k = Coefficient of stress concentration (0.75),

f = Coefficient of safety (1.5), and

σ_y = Yield stress, 520 MPa.

By substituting above values in the following equation, rotor shaft diameter was calculated as:

$$d = \sqrt[3]{\frac{16\, M_s}{\tau \pi}}$$

or

$$d = \sqrt[3]{\frac{16 \times 1451}{1530.6 \times 3.14}}$$

$$= 16.9 \text{ mm} \qquad \ldots(5)$$

In order take into account fluctuating load during the operation, diameter of the rotor shaft was selected higher than the calculated value as 18 mm.

Design of Cutting Blade

For cutter blade design, number of blade, cutting width and thickness were important parameters. During cutting, blades would be subjected to shearing as well as bending stresses. Total working width of the weeder was 400mm having two rotor shafts, each of length of 200mm. Total of 16blades were provided with cutting width of 50mm. Therefore, four blades were provided on each flange and four flanges were mounted, two on each rotor shaft.

The soil force acting on the blade (K_e) was calculated by the following equation:

$$K_e = \frac{K_s C_p}{i\, Z_{eMe}} \qquad \ldots(6)$$

Where,

K_s = Maximum tangential force, kg,

C_p = Coefficient of tangential force,

i = Number of flanges,

Z_e = Number of blades on each side of the flanges, and

n_e = Number of blades which act jointly on the soil by total number of blades for particular flange.

By solving eqn. 6, the soil force acting on the blade (K_e) was determined as 145.1 kg.

The dimensions of the blades are given in Fig. 1. The values of b_e, h_e, S_s and S_1 were equal to 0.6, 2.5, 5.0 and 30 mm, respectively.

Considering the shape of the blades, the bending stress (σ_{zg}), shear stress (τ_{skt}), and equivalent stress (σ_{zt}) can be calculated by the following equations (Bernacki *et al.*, 1972):

$$\sigma_{zg} = 6\,\frac{K_e S}{b_e h_e^2} \qquad \ldots(7)$$

$$\tau_{skt} = \frac{3\,K_e S_1}{\left(\frac{h_e}{b_e} - 0.63\right) b_e^3} \qquad \ldots(8)$$

$$\sigma_{zt} = \sqrt{\sigma_{zg}^2 + 4\,\tau_{skt}^2} \qquad \ldots(9)$$

Where,

σ_{zg} = bending stress, MPa,

τ_{skt} = shear stress, MPa, and

σ_{zt} = equivalent stress, MPa.

By solving Eqn. 7, 8 and 9, the bending stress, shear stress and equivalent stress were determined as 85.40 MPa, 167.65 MPa and 346.0 MPa, respectively.

After determining dimensions of the major components of the weeder, dimensions of other parts were considered accordingly.

Machine Components

Based on design values of different components, an engine operated ridge profile weeder was fabricated in the workshop of the Division of Agricultural Engineering, IARI, New Delhi. A power source of 2.20 kW (Yamaha-

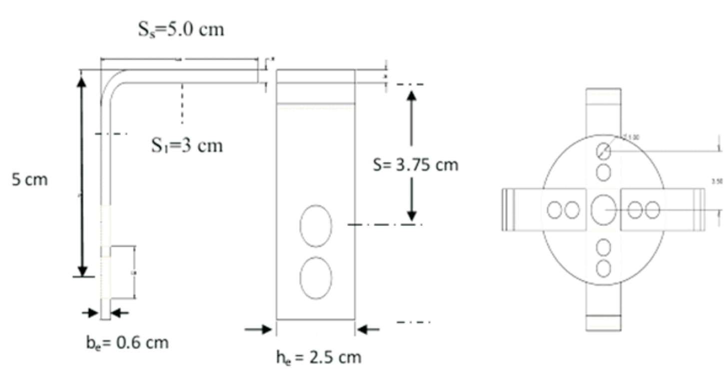

Fig. 1: Specifications of L-type blade

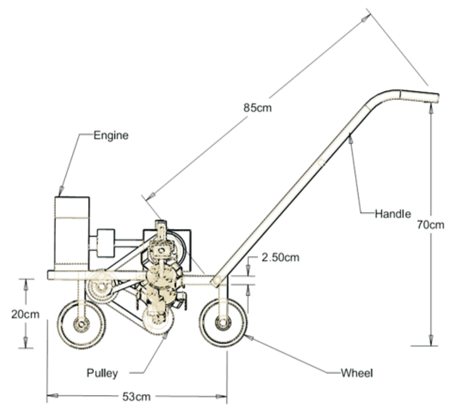

Fig. 2: Side view of ridge profile power weeder

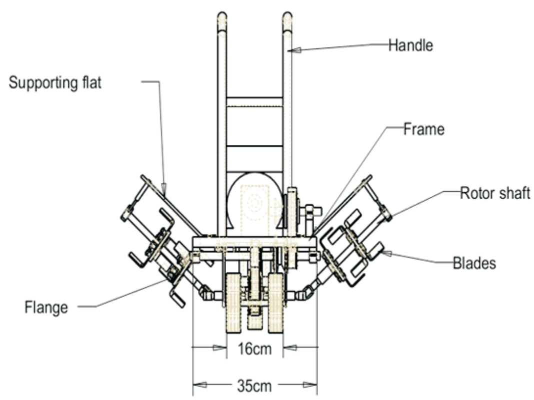

Fig. 3: Front view of ridge profile power weeder

Birla), 3600 rpm, two-stroke, petrol-start kerosene-run engine was selected, which was capable of providing the required power. Side and front view of the ridge profile power weeder is shown in Figs. 2 and 3, respectively.

Main frame

A main frame of 530 mm length, 200 mm height and 350mm width having two handles was made of M.S. square having size of 25 × 25 × 3 mm. The frame was made rigid so as to provide support to the rotor blades, engine, wheels and handles. The weight of the machine was 53 kg with all assemblies and engine.

Rotor shaft and blades

The length of rotor shaft (18 mm diameter) was 200mm, so that it could cover the entire ridge surface. Three type of blades were selected viz, L- type, C- type and Flat- type. The blades of the rotor was made of mild steel flat of 25 mm width and 6 mm thickness. The radius of the rotor blades was kept as 50 mm. Sixteen blades of cutting width 50 mm were fabricated, and four blades were provided on each flange. Each rotor shaft was provided with one pair of flange, providing total width of cutting of 200 mm. The rotor blades were fitted on mild steel flange of 90 mm diameter and 8 mm thickness.

Transportation wheels

Three rubber wheels, each of 140 mm in diameter and 40mm

Table 1. Specifications of developed prototype weeder

Sl. No.	Component	Overall dimension	Material of construction
1.	Overall Length	1220mm	25 × 25 × 4 mm
	Width	680 mm	M.S. square section
	Height	700 mm	
2.	Soil cutting unit		
	Rotor shaft (2)	Φ = 18 mm, 200 mm	Rolled steel
	Flange (4)	Φ = 90 mm, 8 mm	M.S
	Cutting blade (16)	25 x 3 mm	M.S. Flat
	Universal joint (2)	Φ_i = 22 mm	Forged steel
3.	Power transmission system		
	No. of step-up pulley	2	Cast iron
	No. of V- belt (B- section)	2	Rubber
4.	Handle	Φ = 25 mm	G.I pipe
5.	Wheel (3)	Φ = 150 mm	M.S
6.	Total Weight	53 kg	-

in width, were fitted on a shaft with bush. Provision was made to raise or lower the wheels as per requirement, so that the frame of the weeder could remain above the top of ridge.

Handle

The handle of the power weeder was made of 25 mm diameter conduit pipe (16 gauge) and fitted to the frame. Handle height was kept at 700 mm with provision of adjustement as per the convenience of the operator.

Power transmission system

The power transmission system consisted of speed reduction gearbox (10:1), belt and two-step pullies. Power was transmitted from engine to intermediate shaft, and from intermediate shaft to the rotor blade shaft.

Specifications of the power weeder is given in Tavle 1.

Performance Evaluation

Prototype of ridge profile power weeder was tested under field conditions in sandy loam soil for its performance evaluation with different combinations of soil-machine parameters (Fig. 4). A 900 m^2 field was divided into three equal block sizes according to randomized complete block design. The ridge profile power weeder was tested for 2 h in the field at each level of soil moisture content. The following performance indicators were calculated using the observed data in the field:

Weeding efficiency

Weeding efficiency is a ratio of the number of weeds removed by a weeder and the number present in unit area

Fig. 4: Field evaluation of ridge profile power weeder

and is expressed as:

$$\text{Weeding efficiency, (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \qquad \ldots(10)$$

Where,

W_1 = Number of weeds before weeding, and

W_2 = Number of weeds after weeding.

Plant damage

Plant damage (ratio of number of plants damaged in a row to the number of plants present in that row) was calculated by the following equation:

$$\text{Plant damage, \%} = \left\{1 - \left(\frac{q}{p}\right)\right\} \times 100 \qquad \ldots(11)$$

Where,

q = Number of plants in a 10 m row length after weeding, and

p = Number of plants in a 10 m row length before weeding.

Field capacity

Field capacity (ha.h^{-1}) was computed by recording the area weeded during each trial run in a given time interval. With the help of stopwatch, time was recorded for respective trial run along with area covered.

Performance index

The performance of the weeder was assessed through performance index (PI) using the following relation:

$$PI = \frac{FC \times (100 - PD) \times WE}{P} \qquad \ldots(12)$$

Where,

FC = Field capacity, ha.h^{-1}

PD = Plant damage, %

WE = Weeding efficiency, % and

P = Power, hp.

Field machine index

For calculating field machine index, total time required to complete one test run and time loss in turning was recorded with the help of a stopwatch. The theoretical time required at selected forward speed was calculated. Field machine index was calculated as:

$$FMI = \frac{T_p - T_o - T_t}{T_p - T_o} \times 100 \quad \ldots(13)$$

Where,

T_p = Total productive time, s,

T_O = Theoretical time, s, and

T_t = Time loss in turning, s.

RESULTS AND DISCUSSION

Performance of Weeder at Different Soil Moisture Content

The performance parameter as a function of moisture content was recorded for the powered weeder in the experimental field (Fig. 4). It can be seen from Fig.5 that weeding efficiency increased with increase in moisture content at each rotor shaft speed, since soil compaction was optimum at high moisture content which made weeds easily susceptible to mechanical shear. However, plant damage percentage was not significantly influenced by soil moisture content.

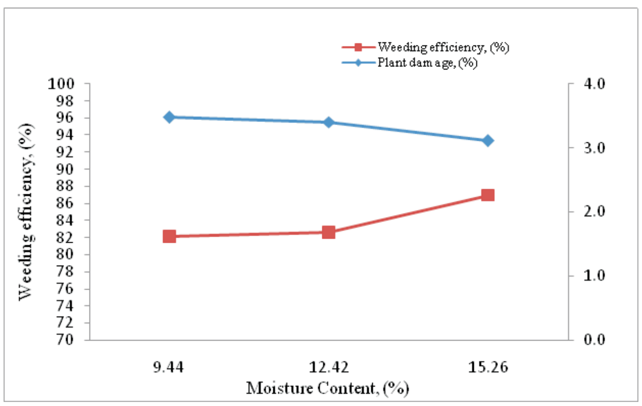

Fig. 5: Performance parameters of weeder as a function of soil moisture content

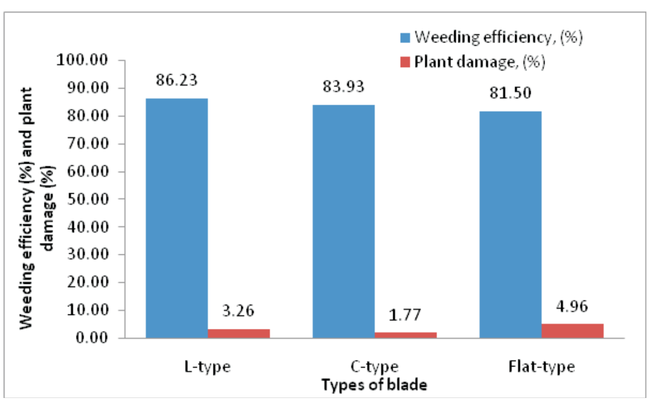

Fig. 6: Performance parameters of weeder with different types of blade

Performance of Different Types of Blade

Performance of the weeder with different types of blade is shown in Fig. 6. Highest weeding efficiency was recorded for L-type blade (86.23%), and lowest for flat-type blade. L-type blade had highest weeding efficiency due to increased soil contact with uniform cutting depth throughout its cutting width. Flat-blade was found to be inferior among all three types of blade owing to its poor cutting ability. Plant damage was 3.29%, 1.77% and 4.96 % for L-type, C-type and flat-type weeder, respectively. Lower percentage of plant damage occurred with C-type blade due to its curvature at the end. Plant damage percentage was higher in case of flat-type blade owing to its larger projected surface area on the plant canopy.

Performance parameters of the weeder with C-type blade during field operation are presented in Table 2. Weeding efficiency was notably higher (91.37%) in case of C-blade with minimal plant damage of 2.66 per cent. The average field capacity was 0.08 ha.h^{-1} (Thorat, 2013) for continuous operation of the weeder at an average forward speed of 1.33 km.h^{-1}.The machine not being self-propelled, the operator required more time to shift it to the next row at the field borders. Therefore, relatively low field machine index was recorded. The results were similar as earlier reported by Srinivas *et al.* (2010) on evaluation of weeders.

Table 2. Field performances of ridge profile power weeder

Sl. No.	Performance parameter	Result
1.	Weeding efficiency,%	91.37
2.	Plant damage, %	2.66
3.	Average forward speed, km.h^{-1}	1.33
4.	Field capacity, ha.h^{-1}	0.08
5.	Performance index	192.34
6.	Average field machine index, %	66.51

CONCLUSIONS

A manually operated ridge profile power weeder operated by a 2.2 kW engine and weighing 53 kg was designed and developed for weeding with minimum plant damage and power requirement. C-type of blades (length, cutting width and thickness of 100 mm, 50 mm and 6 mm, respectively) operated by rotor shaft of 18 mm in diameter and 200 mm in length was found to be superior among the three types with satisfactory weeding efficiency (83.93 %) and minimal plant damage (1.77%). Machine performance in sandy loam soil indicated that with soil moisture increasing from 9.44 to 15.26 % (w.b), weeding efficiency increased from 82.10 to 86.94 per cent. Optimal field parameters for C-type blade were soil moisture content (15.26±0.96%), mean weeding efficiency (83.93 %), plant damage (1.77%) and field capacity (0.08 $ha.h^{-1}$) at forward speed of 1.33 $km.h^{-1}$.

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