RESEARCH PAPER International Journal of Agricultural Engineering | Volume 11 | Issue 1 | April, 2018 | 64-72
e ISSN–0976–7223 ■ Visit us : *www.researchjournal.co.in* ■ **DOI: 10.15740/HAS/IJAE/11.1/64-72**

Field performance evaluation of L-shaped blade rotary tiller cum inter row weeder

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Received : 16.01.2018; **Revised :** 10.02.2018; **Accepted :** 19.02.2018

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■ **ABSTRACT :** Weeding is one of the most difficult tasks on an agriculture farm, especially so in the humid tropical regions. Due to lack of suitable technology weed pose a major problem in Indian agriculture. A self-propelled rotary tiller machine was designed and developed for weeding purpose without damaging of plants. It comprises of 'L-shaped' blades mounted on flanges that was affixed to a shaft driven by a 5 HP diesel engine. The field performance evaluation of machine was calculated based on theoretical field capacity, effective field capacity and field efficiency and was found to be 0.26 ha/h, 0.19 ha/h and 73 per cent, respectively. The mean mass diameter and power requirement was minimum 1.64 mm and 1.05 kW at λ-ratio of 5.65 and was maximum 2.24 mm and 1.25kW at λ-ratio of 3.26, respectively. The 16 per cent less power required when the operating speed was 0.64 m/s. The average weeding efficiency of machine and fuel consumption was obtain 94 per cent and 1.6 l/h (8.42 l/ha). The operation cost was calculated 184 Rs./h (970 Rs./ha).

■ **KEY WORDS :** Rotary tiller, L-shaped, Performance, Weeding efficiency

■ **HOW TO CITE THIS PAPER :** Dhruwe, N.K., Sahu, S., Raghuwanshi, R. and Nishad, P. K. (2018). Field performance evaluation of L-shaped blade rotary tiller cum inter row weeder. *Internat. J. Agric. Engg.*, **11**(1) : 64-72, **DOI: 10.15740/HAS/IJAE/11.1/64-72.**

Indian agriculture is of the subsistence type and, therefore, not much scope for increasing cultivable area. Hence, it is imperative to improve the yield by intensive agriculture, which necessitates better use of through best management practices. Weeding and intercultural is one of the critical management practices which have proportionate effect on the soil moisture conservation, nutrients loss in rain fed areas and finally affects the crop yields significantly. Sickle, *Khurpi* and hoes are the traditional equipment which is used for weeding purpose but this method has very low field capacity and fatigue full for human.

Common ways for controlling weeds include mechanical, chemical, biological and agronomical ones. Mechanical control, which is performed by hand and mechanical weeders have specific importance from agronomical and conformity with environmental condition points of view (Gite and Yadav, 1990). Mechanical control not only eradicates weed between rows, but also softens superficial soil and enhances aeration of soil. Hand weeding is overwhelming and hurts workers who are mostly women. Depending on weed density and species in the field, labour requirement for weeding varied between 10 to 15 persons per hectare in paddy fields. Concerning growing trend of labour wage during recent years, remarkable part of rice production cost is allotted to this stage. Many researchers have compared field performance and efficiency of weeders with hand weeding method.

Manuwa *et al*. (2009) designed and developed a power weeder with working width of 0.24 m for weeding in row crop planting. Effective field capacity, fuel consumption and field efficiency of the machine were 0.53 ha h^{-1}, 0.7 Lh^{-1} and 95 per cent, respectively. Parida (2002) modified IRRI conical weeder and evaluated its field performance in paddy fields. Results revealed that under experimental conditions, field capacity and field efficiency of the weeder were found to be 0.2 ha h^{-1} and 80 per cent, respectively. Other studies in this field showed that the application of weeder would increase field capacity and decrease time and cost of weeding operation (Kumar *et al.*, 2000; Goel *et al.*, 2008; Singh, 1992 and Biswas *et al.*, 2000). Review of reports show that there is a little information on the efficiency of manually operated and power weeders compared to hand weeding in low land soybean fields.

Therefore, the objective of this study was to evaluate field performance of rotary tiller cum inter-row weeder for developing appropriate mechanical control practice in the soybean fields.

METHODOLOGY

Description of machine:

A self-propelled rotary tiller (Fig. A), comprising of 'L-shaped' blades mounted on flanges that are affixed to a shaft that is driven by a 5 hp diesel engine. Rotary tiller is an active tillage tool that processes the soil at a speed that is different from the forward travel speed. With respect to depth of tillage, this is unique in its operation, the actual depth of tillage for each blade changes throughout the rotational path of cutting blade. It has superior soil mixing and pulverization capability in comparison to passive tools. Various factors affect energy requirements of rotary tillage operations. These factors are influenced by soil conditions, operational conditions and machine configuration. The rotary blades are set to allow down cut rotation only. Sufficient spacing is left in-between two rotor assembly so that the machine can be used in intercultural operations also. It can be easily inserts into the cropped field and remove weeds by operating in shallow depth without damaging the crop. It is necessary that the crop shown in uniform row to row spacing. It requires special attention to operate straight, along the row. The weeds are cut due to rotary action and deposited in the soil so that it works as biological manure. Machine is equipped with pneumatic wheels, so that it can easily move on road as well as on field. Negative draft helps to move the machine in forward direction. The impact of rotating blade on soil helps to create tangential thrust force to push the machine forward with negligible slippage (Dhruwe, 2018).

Fig. A : **L-shaped blade rotary tiller cum inter-row weeder**

Table A: Technical specification of machine

Particular	Description
Power unit (Diesel engine)	5 hp
Engine speed (rpm)	2600
Weight of engine (kg)	45
Weight of machine (kg)	150
Ground clearance of frame (mm)	550
L×W×H of machine (mm)	1800×650×100
Type of blade	L-shaped
L×W×T of blade (mm)	80×65×6
Shearing angle of blade (°)	20
Number of blade per flange	4
D×W×T of flange mm	160×260×12
Spacing between two unit	100
Maximum speed of operation (m/s)	1.11
Maximum speed of rotor (m/s)	3.35

Performance evaluation factors of machine:

The various parameters which influence the performance of machine are measured as follows:

Bulk density of soil :

It is expressed as mass of soil per unit volume. Core cutter was used for taking the sample of soil from the ground at desired depth. The core cutter made by a metallic cylinder of known volume keep vertically on the randomly selected plane surface of the field and placed the collar at the top of the cylinder and hammered until the cylinder fully entered into the ground. Then remove the soil around the outside of the cylinder and took out the cylinder with soil by cutting the soil from the bottom, then weight the soil sample after removing cylinder (M). This all process was repeated for different moisture content. The bulk density can be determined by following formula:

$$\text{Bulk density } (\frac{kg}{m^3}) = \frac{\text{Mass of soil sample (M)}}{\text{Valume of cylinder (V)}} \quad ....(1)$$

Soil moisture content :

The soil moisture content was measured with the help of oven dried method. The five soil samples of 50 gram were taken at the different depth and kept them in hot air oven dryer at for 24 hours. Weigh the samples after 24 hours. The moisture content (wet basis) can be calculated by following eq.

$$MC\ (\%, wb) = \frac{W_1 - W_2}{W_1} \times 100 \quad ....(2)$$

where;

W_1 = Weight of soil before dying, (g) and

W_2 = Weight of soil after dying, (g).

Cone index of soil :

The force required to press the circular cone through the soil expressed in kPa, is an index of soil strength called the "cone index". It shows the penetration resistance of the soil. The soil cone penetrometer was used for measuring cone index of soil. First set the gauge of penetrometer at zero. Hold the penetrometer in a vertical position on the surface. The cone was pushed into the soil at a uniform rate of approximately 30 mm/sec the surface reading was measured at the instant the base of the cone was flushed with the soil surface. The readings were taken at the different depth interval, 50 mm, 100 mm and 150 mm. Cone index of soil was determined by the following formula:

$$\text{Cone index (kgf)} = \frac{F + W}{A} \quad ....(3)$$

where;

F = Force applied on the cone penetrometer, (kgf);

W = Weight of cone penetrometer, (kgf) and

A = Area of the base of the cone (cm^2).

Depth of operation :

The furrow was cleaned first, and depth of cut was measured in a furrow length at 3 m distance. The measurement was done at five different places. The average depth of cut was calculated using formula given below:

$$\text{Depth of operation (m)} = \frac{d_1 + d_2 + d_3 + d_4 + d_5}{5} \quad ....(4)$$

Effective width of cut:

Measure the marked untilled land at an interval of about 3 m in length. Take the average of readings obtained, in order to get average width of untilled strip (B). The difference of A and B would give the width of operation.

Forward speed of machine :

Marked the known distance on the field, with the help of stop watch note total the time, required to marked distance travelled by the machine the forward velocity of operation was measured by the following equation (Hunt, 1995).

$$\text{Forward speed (m/s)} = \frac{\text{Distance}}{\text{Time}} \quad .....(5)$$

Effective field capacity:

The effective field capacity is the ratio of the actual area covered by machine per unit time. It included the time losses (turning losses). It is measured by operating the rotary tiller continuously on the field and thereafter the area covered and time required was noted thus the effective field capacity was measured in hectare per hour.

Theoretical field capacity:

Theoretical field capacity is defined as the product of theoretical working width of implement to the speed of operation. Thus the area covered per unit time is measured. It is expressed in hectare per hour.

$$\text{Theoretical field capacity } (\frac{ha}{hr}) = \frac{W \times V_f \times 3600}{1000} \quad ......(6)$$

where,

W = Rated width of implement (m) and

V_f = Forward speed of machine (m/sec)

Field efficiency :

The field efficiency is the ratio of effective field capacity to the theoretical field capacity. It is expressed in per cent and calculated using by following question (Hunt, 1995):

$$\text{Field efficiency} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100 \qquad .....(7)$$

Weeding efficiency:

To determine the weeding efficiency a square ring (30 x 30 cm) was placed at random in the field before starting the test and the number of weeds was counted. The weeding efficiency of the weeder was calculated by the following equation (Remesan *et al.*, 2007):

$$\text{Weeding efficiency} = \frac{N_1 - N_2}{N_1} \times 100 \qquad .....(8)$$

where;

N_1 = Number of weeds before operation.

N_2 = Number of weeds after operation.

Pulverization index:

The value of soil pulverisation index was determined by following method.

$$\text{Pulverization index} = \frac{\text{Sum of product}}{100} \qquad .....(9)$$

Mean mass diameter (MMD):

Mean mass diameter is the measure of size of soil aggregates. After the completing the operation, the soil sample were collected from the area of 150 x 150 mm and to the depth of operation. Weigh accurately the collected material and pass it through a set of sieves with different aperture sizes (Table B). The value of mean mass diameter was calculated as following formula:

$$\text{MMD(mm)} = \frac{\text{Sum of product of sieve size and soil mass retained}}{\text{Total mass of soil}} \qquad .(10)$$

Rotational velocity of rotor (rpm):

Digital contacting type tachometer was used for measuring the rotational speed of rotor. The cone of tachometer needle was tightly held on the hole of the rotating shaft. The speed of the tachometer needle was as same as the speed of the rotating shaft. Thus, the digital tachometer displays the reading in terms of rpm. Set the speed of rotor at maximum rpm.

Bite length:

The bite length or tilling pitch is defined as the distance between the two continuous cut on the horizontal plane by two adjacent blades of the rotor lies on the same direction of one flange. It is denoted by L_b, expressed as:

$$L_b = \frac{V_f \times 60}{N \times Z} \qquad .....(11)$$

where,

V_f = Forward velocity of machine (m/sec)

N = Rotational speed of rotor (rpm) and

Z = Number of blades lies on one flange in same direction.

Fuel consumption:

For measuring the fuel consumption of machine, first the fuel tank was filled with known quantity of fuel and operates in the field for 1 hour period. After the operation, stop the engine and the fuel remaining in the tank was collected in the calibrated jar. The difference of quantity of fuel poured in the tank and collected after the operation was the fuel consumption of machine per hour.

Total torque requirement :

The total torque requirement is the sum of the torque

Table B : Determination of soil pulverization index

Sieve size (mm)	Mass retain (g)	Mass retain (%)	Multiplication factor	Product	% finer (100-%M)
4.75	3	0.37	7	2.62	99.62
2.36	7	0.87	6	5.25	98.75
1.18	10	1.25	5	6.25	97.50
0.6	43	5.37	4	21.50	92.12
0.3	275	34.37	3	103.12	57.75
0.15	300	37.50	2	75.00	20.25
0.075	118	14.75	1	14.75	5.50
Pan	44	5.50	0	0.00	0.00
	800	100.00		228.50	

requirement by the leg and span of the blade and the idle torque required by the rotor assembly to overcome inertia forces acting on the blades and flanges mounted on the shaft, gear box housing of rotavator. The power required for operating the pump for producing desired hydraulic power to offset the machine at limited period of time.

$$T_{total}=T_{fcleg}+T_{span}+T_{thraw}+T_{idle} \quad \text{...... (12)}$$

Assumptions for calculation:

The calculation was done for determining the absolute value of the forces and total power requirement at a particular angle of blade from the horizontal surface. The values of torque due to the various forces acting upon the rotating L-shape blade discussed previously. These values are related to soil physical and dynamic properties are given (Table C).

Table C: Soil physical and dynamic properties

Soil parameters	Values
Bulk density of soil (N/m^3)	17462
Cohesion force of soil (N/m^3)	12,233
Adhesion force between soil and blade (N/m^3)	8,868
Internal friction angle (°)	33.14
Soil metal friction angle (°)	31.63
Maximum depth of operation (m)	0.08

Total power requirement:

According to Gupta and Vishvanathan (1993) the power requirement of a rotary tiller consists of 0.34 to 0.59 per cent for cutting the soil slices, 30.5 to 72.4 per cent for throwing out soil slices by centrifugal action of rotary blades, 0.96 to 2.45 per cent for overcoming soil-metal friction, 0.62 to 0.99 per cent for soil-soil sliding friction and 23.1 to 64.6 per cent for idle power. This is the power required by a single blade of rotary tiller to overcoming below forces in mentioned circumstances.

$$P_t\,(kW) = \frac{2 \times \pi \times N \times T_{total}}{60000} \quad \text{....(13)}$$

Operational cost estimation:

The sum of fixed cost and variable cost is known as "operational cost". This calculation is done for estimating the operational cost per hour of any implement so that we can identify the economic viability of operation. In this phenomenon two terms fixed cost and variable cost are considered.

RESULTS AND DISCUSSION

The estimation of power requirement is done theoretically by referencing the existing models was while qualitative parameters are evaluated by operating the machine on the field were analysis of output in the laboratory. The machine equipped with L-shape blade; impact, cut and throw the soil with desired rotary action, idle power requirement (inertia forces for rotating elements), and power requirement to move the machine on the field with permissible speed all these factors required torque or power to overcoming various forces. Considering all these parameters to identify the size of prime mover (engine) was the prime challenge. Thereafter, some inputs like kinematic parameter ($\lambda - ratio$) and soil moisture content are mentioned as constant to evaluate the performance of developed machine.

Behaviour of torque requirement of blade:

The analytical models for prediction the power requirements of rotating blade are established by referencing the angle of rotation of blade. The behaviour of various forces, allow to increase or decrease their magnitude with the angle of rotation, made from horizontal rotor axis to instantaneous position of blade. Soil cutting starts with entry of blade into the ground at the angle of 30^0 from the horizontal. But when the cutting angle goes up to 114^0 the blade exit from the ground and there is no soil to cut so the cutting force or torque suddenly goes to zero (excluding idle torque) as shown in Fig. 1. The peak value of this torque was predicted 3.106 Nm at the maximum depth of cut (0.08m) and the angle of 90^0.

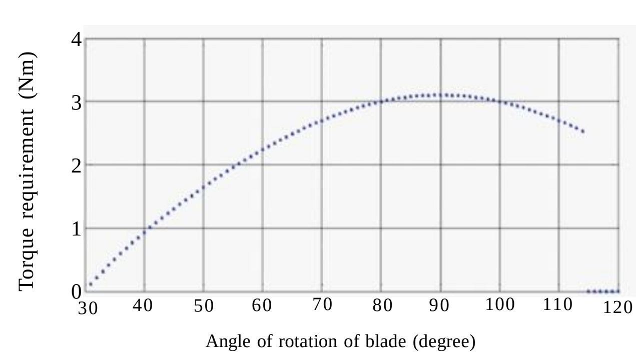

Fig. 1 : Torque required by the leg of blade to overcome soil cutting forces with angle of rotation

Fig. 2 shows the nature of the torque required to overcoming from the soil-metal friction forces from the leg of the blade the value torque requirement increases due to the area of contact of blade increases as the blade starts penetration into the ground. The active earth pressure also increase with the increasing in depth of cut. This torque is minimum at the entry and highest (3.424Nm) at the was maximum depth of operation.

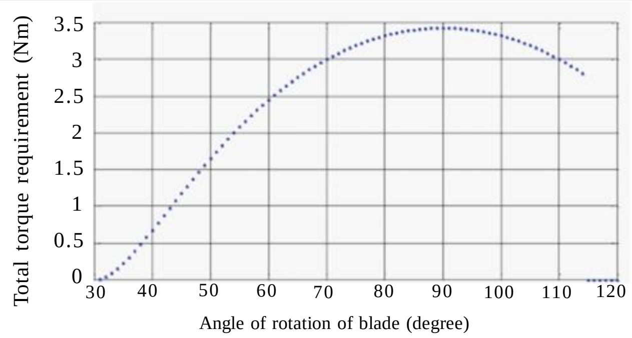

Fig. 2 : Torque required by the leg of blade to overcome frictional forces with angle of rotation

Fig. 3 represents the behaviour of the torque required to throw the mass of cut soil slice during the operation. Maximum volume of cut soil slice at the top of the ground and it gradually decreases as the blade goes down to the ground surface. This is because of the trochoidal motion. The maximum and minimum torque was calculated at the angle of 30^0 and 114^0, respectively at the maximum set tillage depth 0.05 m.

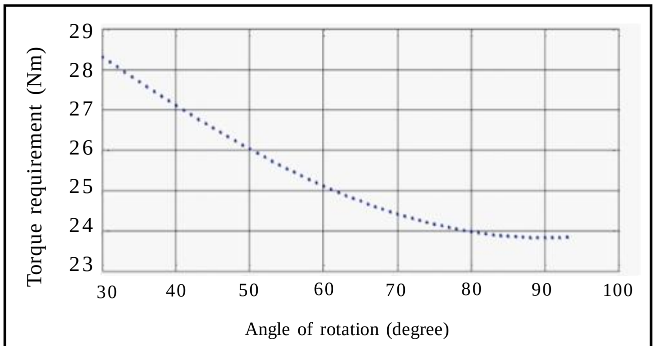

Fig. 3 : Nature torque required to throw the cut soil slice by the span of the blade with angle of rotation

Assessment of trochoildal path:

The rotary tiller consists by an active tillage tool; which process the soil with dual action. The blades of tiller rotates as well as moves forward in direction this action makes the trajectory of the path trochoidal in shape. In Fig. 4 the trajectory of two adjacent rotating blades are shown, mounted on the same flange. The red and blue colour shows the trajectory of first and second blade, respectively while the dark black colour represent the depth of operation 0.08 m. The first blade start to cut the soil and complete their two revolutions and second blade cuts just after first blade by travelling the distance equal to the bite length.

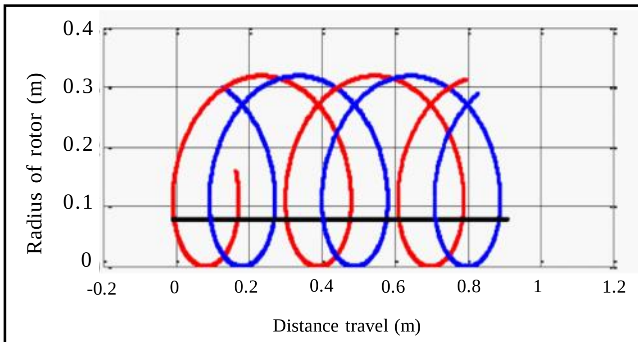

Fig. 4 : Trajectory formed due to rotary and forward motion of blade

Soil metal friction parameters:

The soil metal friction parameters were determined by using a typical graph of the average maximum frictional stress versus the normal stress for the soil at the experimental site at a fixed depth and soil water content in this case the slope and the intercept for a graph of the average maximum friction shear stress against the normal stress defines the angle of soil-metal friction (tan¢). Table 1 reveals that the values of applied

Table 1: Applied normal stress and corresponding shear stress values at 15.60 per cent moisture content and 1780 kg/m^3 bulk density

Normal stress (kg/cm^2)	Dial reading	Least count (kg)	Total shear load (kg)	Shear stress (kg/cm^2)
0.1	30.0	0.2	6.00	0.166
0.2	40.0	0.2	8.00	0.222
0.3	47.0	0.2	9.40	0.261
0.4	60.5	0.2	10.3	0.335
0.5	75.0	0.2	15.0	0.416

normal stress and corresponding shear stress values obtained during experiments for determination of soil cohesive force and internal friction angle at 15.60 per cent MC and 1780 kg/m^3 bulk density.

The slope and intercept of such graphs define the tangent of the angle of soil-soil friction and cohesion force, respectively in the coulomb's equation, therefore, the coulomb's shear stress eq. (14) for Fig. 5. In equation the soil cohesion (C_c) for the soil tested was Pascal (N/m^2) and the internal angle of friction of the soil, ϕ was given by the co-efficient of the normal stress.

²:= 9276+0.4529$\pm_n$ ......(14)

¤:= $\tan^{-1}$(0.4529)=24.37° ......(15)

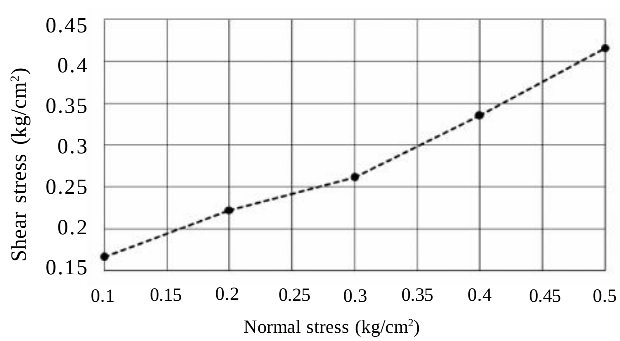

Fig. 5 : Relationship between normal stress and shear stress values at soil-metal failure

Table 2 shows the values of applied normal stress and corresponding shear stress values obtained during experiments for determination of soil adhesive force and external friction angle at 15.60 per cent moisture content and 1780kg/m^3 bulk density.

The slope and intercept of such graphs define the tangent of the angle of soil-metal friction and adhesion force, respectively in the coulomb's equation, therefore, the coulomb's shear stress equation (16) for Fig. 6. In equation the soil adhesion factor (C_a) for the soil tested is Pascal (N/m^2) and the external angle of friction of the soil and metal, is given by the co-efficient of the normal stress.

²:= 6965+0.3922$\pm_n$ ......(16)

¢:= $\tan^{-1}$(0.3922)=21.41° ......(17)

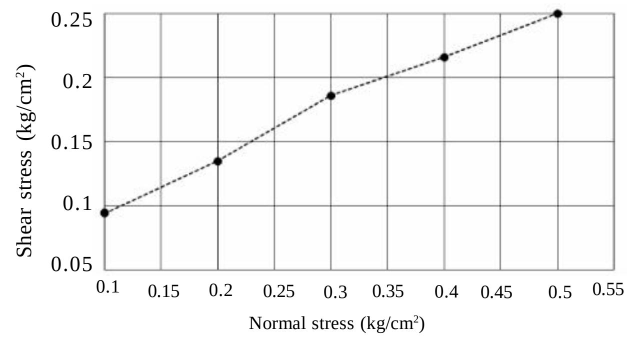

Fig. 6 : Relationship between normal stress and shear stress values at soil-metal failure

Effect of forward speed on kinematic parameters (ª) and the bite length:

In our case the kinematic parameter was influenced by the forward velocity of machine while the other parameters (*i.e.* radius, rotational speed of the rotor and the depth of operation) remain constant. The machine was operated with the four forward velocities and the distance travel per unit time was increased by increasing the operational speed so the length of bite also increases. The bite length was calculated 0.09, 0.104, 0.116 and 0.154 m, respectively.

Table 4 showed the values of mean mass diameter of pulverized soil, power required by single 'L-shape' blade and lambda ratio. It indicates that the particle diameter of soil decreases by increases ª ratio. The nature of power requirement of rotary blades was

Table 2 : Applied normal stress and corresponding shear stress values at 15.60 per cent moisture content and 1780 kg/m^3 bulk density

Normal stress (kg/cm^2)	Dial reading	Least count (kg)	Total shear load (kg)	Shear stress (kg/cm^2)
0.1	17.0	0.2	3.40	0.094
0.2	24.4	0.2	4.88	0.135
0.3	33.5	0.2	6.70	0.186
0.4	39.0	0.2	7.80	0.216
0.5	45.0	0.2	9.00	0.250

Table 3: Effect of forward speed on kinematic parameters and bite length of rotor

Forward speed of machine, m/s (V_f)	Peripheral velocity of rotor, m/s (V_{cir})	Speed of rotor (rpm)	Kinematic parameter $\left(\lambda = \frac{V_{cir}}{V_f}\right)$	Bite length, m $\left(L_b = \frac{V_f x 60}{N x Z}\right)$
0.64	3.61	216	5.65	0.09
0.75	3.61	216	4.83	0.10
0.83	3.61	216	4.34	0.12
1.11	3.61	216	3.26	0.15

Table 4 : Effect of different λ ratio on mean mass diameter of soil and power requirement to process the soil

λ – *ratio*	Mean mass diameter (mm)	Power requirement (kW)
5.65	1.64	1.05
4.83	1.86	1.09
4.34	2.16	1.14
3.26	2.42	1.25

increased as the ratio decreased, because of increasing in forward velocity the bite length increases and this is the reason that the more volume of soil mass was cut and thrown in less time. The MMD and power requirement was minimum and 1.64 mm and 1.05kW and was maximum 2.42 mm and 1.25kW at lambda ratio 5.65 and 3.26, respectively.

Conclusion:

The results of the performance evaluation of the developed weeder indicate that the rotor speed, forward speed and blade parameters influence the weeding efficiency, power requirements and pulverization quality.

– The theoretical field capacity, effective field capacity and field efficiency was found 0.26ha/h, 0.19ha/h and 73 per cent, respectively

– The power requirement was minimum and maximum 1.05 kW and 1.25kW at lambda ratio of 5.65 and 3.26, respectively. The 16 per cent less power required when the operating speed was 0.64 m/sec.

– The mean mass diameter was minimum and maximum 1.64 mm and 2.42 mm and at the 5.65 and 3.26 lambda ratios, respectively.

– The average weeding efficiency of machine was found 94 per cent.

– The fuel consumption was found 1.6 lit/h and 8.42 lit/ha.

– The cost of operation was calculated 184 Rs./h and 970 Rs./ha.

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