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Rohit Namdeo
Jawaharlal Nehru Krishi
Vishwavidyalaya, Jabalpur,
Madhya Pradesh, India

Atul Kumar Shrivastava
Jawaharlal Nehru Krishi
Vishwavidyalaya, Jabalpur,
Madhya Pradesh, India

Avinash Kumar
Jawaharlal Nehru Krishi
Vishwavidyalaya, Jabalpur,
Madhya Pradesh, India

Yalaka Nandini
Jawaharlal Nehru Krishi
Vishwavidyalaya, Jabalpur,
Madhya Pradesh, India

Corresponding Author:
Atul Kumar Shrivastava
Jawaharlal Nehru Krishi
Vishwavidyalaya, Jabalpur,
Madhya Pradesh, India

Optimization of the performance parameters of the L-shaped rotary blade for the development of a plastic mulching machine

Rohit Namdeo, Atul Kumar Shrivastava, Avinash Kumar and Yalaka Nandini

Abstract

To develop plastic mulching machine the L-shaped rotary blade is to be used as one component for the soil refinement. This paper covers the part of optimization of L-shaped rotary blade parameters in indoor soil bin that was filled with vertisol, so that the machine's performance can be improve in heavy soil conditions and can resolve the problem of tearing the plastic mulch. The forward speed of operation, rotary blade rpm, and depth of operation were taken as independent variables, and torque and Mean Weight Diameter were taken as a response. To optimize the kinematic parameter (Lambda Ratio) response surface methodology was used. The cone Index (600±50 Kpa) and soil moisture (14-16%) content of the soil were taken constant for all experimental runs.

Keywords: Optimization, mechanization horticulture, plastic mulching

Introduction

Out of several cultivation methods, plastic mulching is one cultivation practice that would benefit the farmers on improve horticulture production. Plastic mulching is the method to cover the soil with thin plastic film, that practice involves various operations *viz.* soil bed preparation, basal doze application, laying of drip, laying and covering of plastic mulch, and punching for the transplanting of the vegetable seedling. This method is used for crops such as tomato (*Lycopersicon esculentum* Mill.), chili peppers (*Capsicum frutenscens* L.), cauliflower (*B. oleracea* L. *var. Botrytis*), cabbage (*Brassica oleracea* L. *var. Capitata*) eggplant (*Solanum melongena* L.), among others. Plastic mulching leads to higher yields (by up to 100% for certain crops), weed suppression, in early-duration crops (by up to one month), gain in root growth, nutrient uptake, earlier ripening, and in some cases the ability to grow certain crops, which would not be possible without the mulch film. Despite the various advantages of plastic mulching, its adoption rate is very low in developing countries, particularly in India. Poor mechanization higher initial investment, the drudgery of farm work, and the absence of user-friendly machines are the principal reasons behind it. Furthermore, the manual mulching process involves time (255 man-h/ha), cost, and drudgery with the necessity of skilled workers. Whereas most of the existing machinery either manual or tractor drawn used only to lay mulch and drip and required a well-prepared field soil condition that involves some tillage operations before laying the mulch. Due to this, the time and the input cost of cultivation increase. In addition, these types of machinery got inefficient while working in heavy soil, especially in vertisol, which resulted in the tearing of mulch film. The technological review on plastic mulch technology revealed scopes for the development of low-cost and user-friendly machines, considering Indian economical, agronomical, and ergonomic factors (Namdeo and Shrivastava 2021) [8]. Therefore to get the benefits of mechanized mulching and to overcome the issue with existing machines an advanced mulch-laying machine was developed. In the developed machine the L-shaped rotary blade is to be used as one component for the soil refinement. This paper covers the part of optimization of L-shaped rotary blade parameters in indoor soil bin that was filled with vertisol, so that the machine's performance can be improve in heavy soil conditions and can resolve the problem of tearing the plastic mulch.

Material and Method

To optimize the kinematic parameter of the L-shaped soil cutting blade the responses were selected (Table 1) as Torque and MWD (Mean weight diameter of the soil particle).

After the tilling of the soil, these performance parameters were measured at three levels of the forward speeds of operation i.e. 1.5, 2, 2.5 km/h, three levels of the rotational speed of the blades (i.e.150,200,250 rpm), and three levels of depths (i.e. 8, 10 and 12 cm) under the controlled soil bin condition. The soil bin was filled with black cotton soil (Vertisol). The cone Index (600±50Kpa) and soil moisture (14-16%) content of the soil were taken constant for all experimental runs.

Table 1: Selected variables for the optimization of L-shaped rotary blade

Independent Variable	Dependent Variable
Forward speed (km/h): 3 levels (1.5,2,2.5) Speed of blade (rpm): 3 level (150,200,250) Depth of operation (cm): 3 levels (8,10, 12)	Torque (Nm) MWD of soil particle (mm)

The Box Behnken Design (BBD) was used in RSM (Response Surface Methodology) was to optimize the effects of the forward speed of operation (km/hr), speed of the blade (rpm), and the depth of operation (cm) on the dependent variables as Torque and MWD under the indoor soil bin conditions.

Development of the test setup

Test setup of the rotary tillage tool consists of the flange to mount the rotary blade and the power transmission system that is driven by the 5 hp dc motor through the belt and pulley drive (Fig 1 a). Adjustment for setting the operational depth was provided. The troque sensor was assosiated with test set up to meaure the troque. The rotary tools (Disc, rotary blades, etc) can be operated in both clockwise and anti-clockwise directions.

Torque Transducer

The testing trolley was equipped with a torque transducer, which comprises a slip ring to measure the torque of the rotary tillage tool. Strain gauges were used on the shaft in between the driving motor and connecting shaft for the effectual torque measurement. A torque signal from the rotating shafts was transferred and converted into the analog through frequency modulation. At the 60 pulses per revaluation, the speed signal was available as TTL (Transistor-Transistor Logic) signal level. The sensor worked on the principle of strain gages and provided an output as an analog signal that was transmitted without contact. That transducer was recommended for measuring both static and dynamic torque. HBM data acquisition system was used to transfer data from transducers to the computer.

A B

Fig 1: (a) Test set up for the rotary blade and rotary tillage tool (b) Torque sensor

Kinematic parameter (λ–ratio)

Soil pulverization is affected by a dimensionally-independent kinematic parameter called λ–ratio. This term was defined by James G. Hendrick and William R. Gill, (1971) [5] as the inverse of the forward velocity of the machine divided by the rotor's peripheral velocity (Equation 1). Changes in the kinematic parameter are proportional to the rotary speed, rotor radius, and forward machine velocity.

$$\lambda = \frac{V_r}{V_f} = \frac{R_w}{V_f} = \frac{2\pi RN}{60\,V_f} \text{ Eq.... } \quad (1)$$

Where,
λ = kinematic parameter (dimensionless);
V_r= peripheral velocity of rotor, (m/s);
V_f = Forward velocity of the machine, (m/s);
R = radius of the rotor, (m); = angular velocity of rotor, (rad/s).

Bite length

The bite length, also known as the tilling pitch, is the horizontal distance between where two consecutive rotor blades mounted on the same flange cut through the soil (Hendrick and Gill, 1971) [5]. It is given by Equation 2 below and is symbolically represented as Lb.

$$L_b = \frac{Vf \times 60}{N \times Z} \text{ Eq.} \dots \quad (2)$$

Where,

V_f = Forward velocity of the machine, (m/s);

N= Rotational speed of the rotor, (rpm), measured by anon–contacting type tachometer; and

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

Experimental Procedure

Experiments were conducted under laboratory conditions in the soil bin. Before starting the experiments, the field soil conditions were simulated in a soil bin to meet the required level of cone index, moisture content, and soil bulk density in the layer of soil. Pulverization of the soil was accomplished by a rotavator thereafter; water was sprayed on the soil to get the desired moisture content. In addition, the soil was leveled on top by using the leveller and compacted by a roller compactor. After each run of the soil, strength was measured through a cone penetrometer. This cone penetrometer was mounted in the test trolley and has provision to move laterally to get reading at different places. The cone Index of soil was measured by operating the cone penetrometer through a hydraulically assisted ram. The reading was taken to a depth of 12 cm at the interval of 2.5 m along the length of the soil bin at the five locations following the method outlined in the ASAE Standards (ASABE 2004) [2].

Testing of the rotary blade

To test L-shaped rotary blades these blades were mounted on both sides of the flange. That flange was mounted on the shaft that rested on the pedestal provided at both sides of the frame. The flange was mounted to one end of the shaft as another end of the shaft comprises the driven pulley. That driven pulley was connected to the shaft of the motor that was mounted on the plate form. The motor was used to drive the shaft of the rotary blade flange. The torque sensor was placed at the shaft of the motor as shown in Figure 1, to measure the torque of the shaft. After soil bed preparation, to conduct the test experiment, the output cables of the torque sensor were connected to the HBM data accusation system. All the initial or residual values of the torque and rpm of rotary blades showing at DAS were nullified. The depth of the rotary blade was set by a screw and rail system provided above the platform of the motor. After setting of the rotary speed of the rotor and forward speed of operation using the start button was pushed to start the experiment. At the same time clicked on the start tool of the Catman easy software to see the live performance of the tool on the performance visualization window. After the end of the experiment, clicked on the stop command and save the torque value that was imposed on the rotary blade in the library for further analysis. A similar procedure was adopted for all the experimental runs.

Measurement of the soil parameter

Moisture content

All three forces cohesion, adhesion, and friction are modified by the amount of water in the soil. When soil is deformed, these forces are what determine the particle size of the soil. When a rotary tiller's cutting blade makes contact with the soil, it causes shear, which can lead to soil failure or deformation. Therefore, the force necessary for soil pulverization is influenced by the soil's moisture content. That's why soil moisture was the most crucial factor influencing rotary tiller efficiency (Kumar Sahu *et al.* 2018) [7]. Digital moisture meters were used to assess the moisture of the soil in the test bed of the soil bin before each experimental run.

Soil bulk density

The bulk density of soil is defined as the ratio of the mass of the soil to its volume. The bulk density of the soil was obtained by employing the core cutter method. Equation 3 was applied to determine the bulk as a ratio of the weight of oven-dried soil samples to the volume of the core cutter.

$$\rho = \frac{M}{V}$$

Where,

ρ = Bulk density of soil, g/cm^3;

M = Mass of soil contained in the core, gram; and

V = Volume of the core cutter, cubic cm.

Measurement of mean weight diameter

The quality of the soil bed for laying the plastic mulch can be evaluated by measuring the particle size of the tilth soil obtained after running the free-rolling disc. To lay plastic mulch without ripping, the soil bed must have a finer particle size. The pulverized soil's MWD was calculated using a mechanical sieve analyzer. The free-rolling disc was run on a simulated filed soil condition in a soil bin, at varying degrees of disc angle, forward speed, and depth of operation. Following this, soil samples were obtained from a 15 cm by 15 cm area at the working depth. Soil samples were dried for 24 hours in a hot air oven dryer at 105 °C. The sieves from a sieve shaker were organized from largest to smallest, starting with the largest sieve at 4.75 mm and going down to 2.36 mm, 1.18 mm, 600 µ, 300 µ, 150 µ, 75 µ, and a pan. (Then, the top sieve was loaded with 800 g of soil from the dried soil sample. To allow soil particles to pass through the largest sieve and be retained on the undersized sieve, the motor was turned on and the sieves were shaken for 10 minutes. Therefore the weight of soil particle that was retained by each sieve was measured. Equation 4 was used to determine the MWD (mean weight diameter) (Kemper and Rosenau 1986) [6].

$$MWD = \sum_{i=1}^{n} \bar{X}_i W_i \text{ Eq.} \dots \quad (4)$$

Where,

$\bar{X}_i$ = The mean dia. of the sieves at which soil retained on a preceding sieve, mm; and

W_i = Fraction of the weight of soil collected from the retained sieve to the total weight of the sample, g

Result and Discussion

To develop the machine the main objective of the test of the L-shaped rotary blade in indoor soil bin conditions was to optimize the kinematic parameters of the disc to develop the rototill raised bed cum mulch and drip laying machine. As the L-shaped rotary blades are to be used as part of the machine to perform the soil refinement so that it will assist to make the clod-free raised bed soil bed for accomplishing the tearing-free laying of mulch.

To develop the plastic mulch laying machine, the performance parameters of the L-shaped rotary blade were optimized, in the indoor soil bin, filled with vertisol.BBD technique was used as per the decided parameters of the experimental design. The results were analyzed and evaluated and the numerical optimization of the performance parameter of the L-shaped rotary blade was carried out by using the BBRD design experiment in the response surface method.

Effect of operational parameter on the Torque of the rotary blade

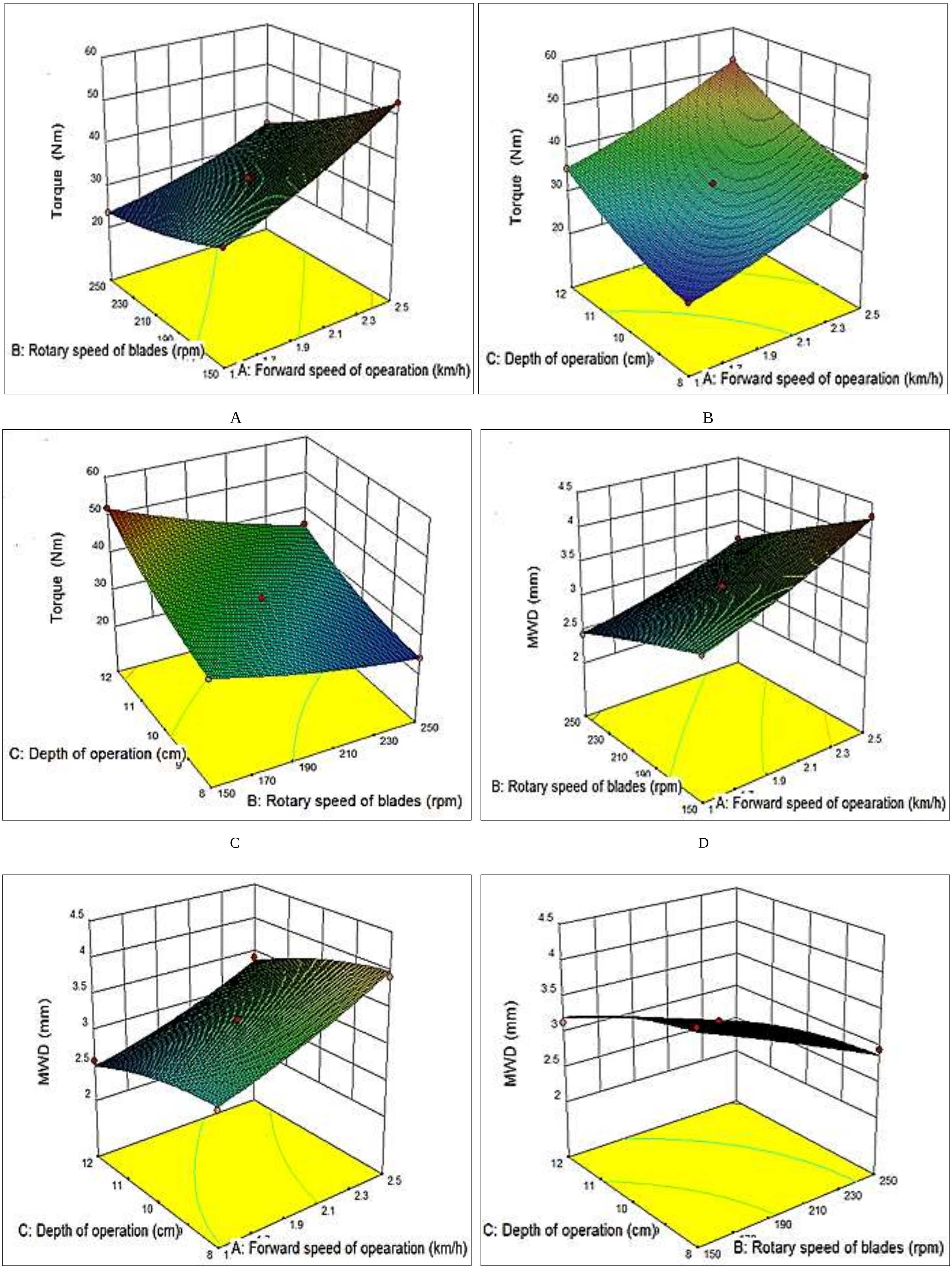
As shown in Table 2 the maximum torque on the L-shaped rotary blade was found to be at 50 Nm at forward seed off 2.5 km/h, 150 rpm rotary speed of the blade and 10 cm depth of operation were as the minimum value was found to be as 22 Nm at 1.5km/h forward speed, 250 rpm of the rotary blade and the 10 cm depth of operation. The effect of the independent parameter such as forward speed of operation, rotary speed of the blade, and depth of operation and their interaction on the torque and Mean mass diameter of the soil was studied as follows

Table 2: Experimental runs and obtained responses for optimization of the L-shaped rotary blade using design expert 10.01

Run	Speed (Km/h)	Rotor Rpm	u/v ratio	Depth of operation (cm)	Torque (Nm)	MWD
1	2	200	7.91	10	33	3.15
2	1.5	150	7.91	10	33	3.16
3	2	200	7.91	10	35	3.251
4	2.5	200	6.33	12	52.06	3.41
5	2.5	200	6.33	8	37.71	3.91
6	2	150	5.93	8	35	3.97
7	1.5	250	13.19	10	23.5	2.43
8	1.5	200	10.55	8	22.71	2.94
9	2	200	7.91	10	35	3.24
10	2.5	250	7.91	10	35	3.23
11	2	200	7.91	10	33	3.26
12	2	150	5.93	12	52	3.14
13	1.5	200	10.55	12	35.48	2.57
14	2	200	7.91	10	35	3.24
15	2.5	150	4.75	10	53	4.31
16	2	250	9.89	12	35.79	2.41
17	2	250	9.89	8	24.44	2.95

Effect of Rotary blade rpm and forward speed on the Torque

At the constant depth of operation, the effect of rotary speed and forward speed of operation and their interaction on the torque required by the rotary blade is shown in Figure 2 (a) at the constant depth of 10 cm, the maxing torque of the L-shaped rotary blades found to be was 53 Nm at 2.5 km /hr speed and 150 rpm of rotary speed whereas the minimum value was 23.5 Nm at 1.5 km/h speed and 250 rpm of the rotary blade. With all rotary speeds, the torque of the blade of the free-rolling discs was found to be significantly (*p*<0.05) increased with an increase in the forward speed of the operation from 1.5 to 2.5 km/h. As shown in Figure 4.18 at 250 rpm when the forward speed is increased from 1.5 to 2.5 km/h the value of torque was found to be increased from 30 to 50 Nm. It is because the same rpm increase in forward speed reduces the u/v ratio (Table 2) resulting in higher values of torque. Although for the different forward speeds of operations, the value of the torque was found to be significantly (*p*<0.05) decreases when the rotary speed of the blades increased. At 2.5 km /h when the rotary speed was increased from 150 to 250 rpm the torque of the rotary blade was found to be decreased from 53 Nm to 35 Nm. It is because of the increase in the u/v ratio. Furthermore, the effect of the interaction of forward speed and rotary speed on the torque of rotary blades was found to be significant (p-value <.05).



A B

C D

E F

Fig 2: Effect of depth of operation and forward speed

At the constant rotary speed of the blade, the effect of depth of operation and forward speed of operation and their interaction on the torque required by the rotary blade is shown in Figure 2 (b). At the constant rotary speed of 200 rpm, the maxing torque of the L-shaped rotary blades found to be was 52.06 Nm at 2.5 km /hr speed and 12 cm depth of operation whereas the minimum value was 22.71 Nm at 1.5 km/h speed and 8 cm depth of operation. At constant rotary rpm, with all depths of operations, the torque of the blade of the free-rolling discs was found to be significantly ($p<0.05$) increased with an increase in the forward speed of the operation from 1.5 to 2.5 km/h. As shown in Figure 2 (b) at 12 cm depth when forward speed is increased from 1.5 to 2.5 km/h the value of torque was found to be increased from 28 to 46 Nm. At 1.5 km/h when the depth was increased from 8 to 12 cm rpm the torque of the rotary blade was found to be increased from 22.71 Nm to 35.48 Nm. It is because of the greater soil strength and more soil volume handled by the blade as compared to the lower depth of operation. This result was found to be similar to those reported by (Gill and Berg 1968; Adams and Furlong 1959) [3, 1]. Furthermore, the effect of the interaction of forward speed and depth of operation on the torque of rotary blades was found to be not significant (p-value >.05).

Effect of the depth of operation and rotary speed of blades on torque

At the constant forward speed of the blade, the effect of depth of operation and rotary speed of blades and their interaction on the torque required by the rotary blade is shown in Figure 2 (c). At the constant forward speed of 2 km/h, the maxing torque of the L-shaped rotary blades found to be was 52 Nm at 150 rpm speed and 12 cm depth of operation whereas the minimum value was 24.4 Nm at 250 rpm and 8 cm depth of operation. At constant forward speed with all depths of operations, the torque of the blade of the free-rolling discs was found to be significantly ($p<0.05$) decreased with an increase in the rotary speed of the blade from 150 to 250 rpm. As shown in Figure 2 (c) at 12 cm depth when rotary speed is increased from 150 to 250 rpm the value of torque was found to be decreased from 42 to 31 Nm. Although for the different rotary speeds, the value of the torque was found to be significantly ($p<0.05$) increases when the depth of operation increased. As shown in Figure 2 (c) when at 250 rpm when the depth was increased from 8 to 12 cm the torque of the rotary blade was found to be increased from 24.44 Nm to 35.79 Nm. Furthermore, the effect of the interaction of rotary speed and depth of operation on the torque of rotary blades was found to be significant (p-value < .01).

ANOVA for Response Surface Quadratic Model of torque

The Model F-value of 700.13 implies the model is significant (Table 3). There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.05 indicate model terms are significant. In this case, A, B, C, AB, BC, A^2, B^2, and C^2 are significant model terms. The P values greater than 0.05 indicate the model terms AC is not significant. The "Lack of Fit F-value" of 0.29 implies the Lack of Fit is not significant relative to the pure error. Non-significant lack of fit is good for the model to fit. The "Pred R-Squared" of 0.99 is in reasonable agreement with the "Adj R-Squared" of 0.9975; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal-to-noise ratio. A ratio greater than 4 is desirable. In this case ratio of 86.75 indicates an adequate signal. This model Equation 5 can be used to predict the torque at a different level of the independent factor.

Torque = 33.6 + 7.885 * A - 6.78375 * B + 6.93375 * C - 2.12 * AB + 0.395 * AC - 1.4125 * BC + 1.35375 * A^2 + 1.171 * B^2 + 2.03625 * C^2 Eq….. (5)

Equation 5 in terms of coded factors can be used to make predictions about the response as torque for given levels of each factor. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Table 3: ANOVA for Response Surface Quadratic Model for the response as Torque

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1311.12	9	145.68	700.13	< 0.0001	*Significant
A-Forward speed of operation	497.39	1	497.39	2390.42	< 0.0001	*
B-Rotary speed of blades	368.15	1	368.15	1769.33	< 0.0001	*
C-Depth of operation	384.62	1	384.62	1848.44	< 0.0001	*
AB	18.06	1	18.06	86.81	< 0.0001	*
AC	0.62	1	0.62	3.00	0.1269	ns
BC	7.98	1	7.98	38.35	0.0004	*
A^2	7.72	1	7.72	37.08	0.0005	*
B^2	5.78	1	5.78	27.76	0.0012	*
C^2	17.46	1	17.46	83.90	< 0.0001	*
Residual	1.46	7	0.21			
Lack of Fit	0.26	3	0.086	0.29	0.8347	not significant
Pure Error	1.20	4	0.30			
Cor Total	1312.58	16				

Std. Dev.	0.46	R-Squared	0.9989
Mean	35.75	Adj R-Squared	0.9975
C.V. %	1.28	Pred R-Squared	0.9954
		Adeq Precision	86.758

*significant ^{ns}non significant

Effect of the operational parameter on the MWD

As shown in Table 2, among the different experimental runs the minimum MWD of 2.41 mm was found to be at the forward seed off 2 km/h, 250 rpm rotary speed of the blade, and 12 cm depth of operation was as the maximum value was found to be as 4.31 mm at 2.5 km/h forward speed, 250 rpm of the rotary blade and the 10 cm depth of operation. The effect of the independent parameter such as forward speed of operation, rotary speed of the blade, and depth of operation and their interaction on the Mean weight diameter of the soil was studied and the results are discussed as follows

Effect of rotary speed and forward speed on MWD

At the constant depth of operation, the effect of rotary speed and forward speed of operation and their interaction on the MWD is shown in Figure 2(d). At the constant depth of 10 cm, the maximum MWD of soil particles was found to be 4.31 mm at 2.5 km /hr speed and 150 rpm of rotary speed whereas the minimum value was 2.43 mm at 1.5 km/h speed and 250 rpm at the rotary blade. At the constant depth of 10 cm, with all rotary speeds, the MWD of soil particles was found to be significantly ($p<0.05$) increased with an increase in the forward speed of the operation from 1.5 to 2.5 km/h. As shown in Figure 2 (d) at 250 rpm when the forward speed is increased from 1.5 to 2.5 km/h the value of MWD was found to be increased from 2.43 to 3.23 mm. It is because of reduction in the u/v ratio resulted in increased MWD.As the u/v ratio increase bite length also increases. Similar results were reported by (H. Bernacki, J. Haman *et al*. 1986; Gill and Berg 1968) [4, 3] Although, for the different forward speeds of operations, the value of the MWD was found to be significantly ($p<0.05$) decreases when the rotary speed of the blades increased. At 2.5 km/h when the rotary speed was increased from 150 to 250 rpm the MWD of the rotary blade was found to be decreased from 4.31 to 3.16 mm. It is because of the increase in the u/v ratio that causes small bite length results in a reduction in MWD. Furthermore, the effect of the interaction of forward speed and rotary speed on the MWD of rotary blades was also found to be significant (p-value <.05).

Effect of depth of operation and forward speed on MWD

At the constant rotary speed of the blade, the effect of depth of operation and forward speed of operation and their interaction on the MWD of the soil particle is shown in Figure 2 (e). At the constant rotary speed of 200 rpm, the maximum value of MWD of soil particles found to be was 3.91 mm at 2.5 km/h speed and 8 cm depth of operation whereas the minimum value was 2.57 mm at 1.5 km/h speed and 12 cm depth of operation. At constant rotary rpm, with all depths of operations, the MWD of the soil particle was found to be significantly ($p<0.05$) increased with an increase in the forward speed of the operation from 1.5 to 2.5 km/h. As shown in Figure 2 (e) at 12 cm depth when forward speed is increased from 1.5 to 2.5 km/h the value of MWD was found to be increased from 2.09 to 2.85 mm. Although for the different forward speeds of operations, the value of the MWD was found to be significantly ($p<0.05$) decreases when the depth of operation increased. At 2.5 km/h when the depth was increased from 8 to 12 cm rpm the MWD of the soil was found to be decreased from 3.91 to 3.41 mm. It is because of greater moisture content at a lower depth. Although, the effect of the interaction of forward speed and depth of operation on the MWD was found to be not significant (p-value >.05).

Effect of the depth and rotary speed on MWD

At the constant forward speed of 2 km/h of the blade, the effect of depth of operation and rotary speed of blades and their interaction on the MWD of the soil particle is shown in Figure 2 (f). At the constant forward speed of 2 km/h, the maximum MWD of the soil particle found to be was 3.97 mm at 150 rpm speed and 8 cm depth of operation whereas the minimum value was 2.41 mm at 250 rpm and 12 cm depth of operation. At constant forward speed with all depths of operations, the MWD was found to be significantly ($p<0.05$) decreased with an increase in the rotary speed of the blade from 150 to 250 rpm. As shown in Figure 2(f) at 12 cm depth when rotary speed is increased from 150 to 250 rpm the value of MWD was found to be significantly decreased ($p<.05$) from 3.08 to 1.99 mm. It is because of an increase in u/v ratio thereby reduction in bite length. Although for the different rotary speeds, the value of the MWD was found to be significantly ($p<0.05$) decreases when the depth of operation increased. At 250 rpm when the depth was increased from 8 to 12 cm the MWD was found to be decreased from 3.97 mm to 3.14 mm. Furthermore, the effect of the interaction of rotary speed and depth of operation on the MWD of soil particles was found to be insignificant (p-value >.05).

Analysis of variance table Response Surface Quadratic model for MWD

As shown in ANOVA Table 4, the model F-value of 75.63 implies the model is significant. Values of "Prob > F" less than 0.05 indicate model terms are significant. In this case, A, B, C, and C^2 are significant model terms. Values greater than 0.05 indicate the model terms are not significant. The "Lack of Fit F-value" of 1.03 implies the Lack of Fit is not significant relative to the pure error for the model to be fit. The "Pred R-Squared" of 0.8648 is in reasonable agreement with the "Adj R-Squared" of 0.9767; i.e. the difference is less than 0.2."Adeq Precision ratio of 30.776 indicates an adequate signal. This model Equation 6 can be used to predict MWD.

Table 4: Analysis of variance table Response Surface Quadratic model for MWD

	Sum of		Mean	F	p-value	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Model	4.09	9	0.45	75.63	< 0.0001	significant
A-Forward speed of operation	1.77	1	1.77	294.01	< 0.0001	
B-Rotary speed of blades	1.58	1	1.58	263.56	< 0.0001	
C-Depth of operation	0.63	1	0.63	104.35	< 0.0001	
AB	0.031	1	0.031	5.10	0.0586	
AC	4.225E-003	1	4.225E-003	0.70	0.4295	
BC	0.021	1	0.021	3.50	0.1036	
A^2	0.022	1	0.022	3.65	0.0978	
B^2	1.342E-003	1	1.342E-003	0.22	0.6510	
C^2	0.036	1	0.036	6.04	0.0436	
Residual	0.042	7	6.011E-003			
Lack of Fit	0.034	3	0.011	5.75	0.0622	not significant
Pure Error	7.925E-003	4	1.981E-003			
Cor Total	4.13	16				

Std. Dev.	0.078	R-Squared	0.9898
Mean	3.21	Adj R-Squared	0.9767
C.V. %	2.42	Pred R-Squared	0.8648
		Adeq Precision	30.776

MWD = $3.2282 + 0.47 * A - 0.445 * B - 0.28 * C - 0.0875 * AB - 0.0325 * AC + 0.0725 * BC + 0.07215 * A^2 - 0.01785 * B^2 - 0.09285 * C^2$Eq….. (6)

Numerical optimization of the performance parameter of L shaped rotary blade

To optimize the performance parameter of the L-shaped rotary blades the constraints were decided as per the functional desirability of the blades (Table 5). The goal and importance were set by proving the inputs in design expert software as shown in Table 5. After setting the criteria the optimized solution was determined using design expert software as shown in Table 6. The numerical optimized values of the independent variable were generated by the design expert software and were found to be 190 rpm rotary speed, 2.5 km/h forward speed, and 11.7 cm depth of operation respectively whereas corresponding predicted values of the responses, torque 53 Nm, MWD 3.5 mm respectively. Although the individual desirability of the parameters was shown in Figure 3 and Figure 4.

Table 5: Constraints for optimization of L-shaped rotary blade

			Lower	Upper	Lower	Upper
Name	**Goal**	**Limit**	**Limit**	**Weight**	**Weight**	**Importance**
A: Forward speed of operation	maximize	1.5	2.5	5	1	5
B: Rotary speed of blades	is target = 190	150	250	1	1	5
C: Depth of operation	is in range	8	12	1	1	5
Torque	is in range	22.71	53	1	1	3
MWD	minimize	2.41	4.31	1	1	3

Table 6: The optimized solutions for L-shaped rotary blade

Number	Forward speed of operation	Rotary speed of blades	Depth of operation	Torque	MWD	Desirability	
1	2.500	190	11.770	53.000	3.514	0.818	Selected
2	2.500	190.407	11.786	53.000	3.506	0.818	
3	2.500	191.124	11.813	53.000	3.493	0.817	

Post-analysis of the optimization

Point prediction through providing the desired operating condition in the software and the predicted response were determined with a 95% of confidence interval. The prediction that is predicted by the model at the optimized independent parameter was found. The experiment was conducted for the validation of the predicted values of responses at optimum operating conditions. These results were validated to authenticate the model. The mean value of the observed torque and MWD was found 52.34 Nm and 3.49 mm against predicted mean value values of 52.60 Nm and 3.53 mm in between the range of 95% CI (Confidence Interval) low to 95% CI high.

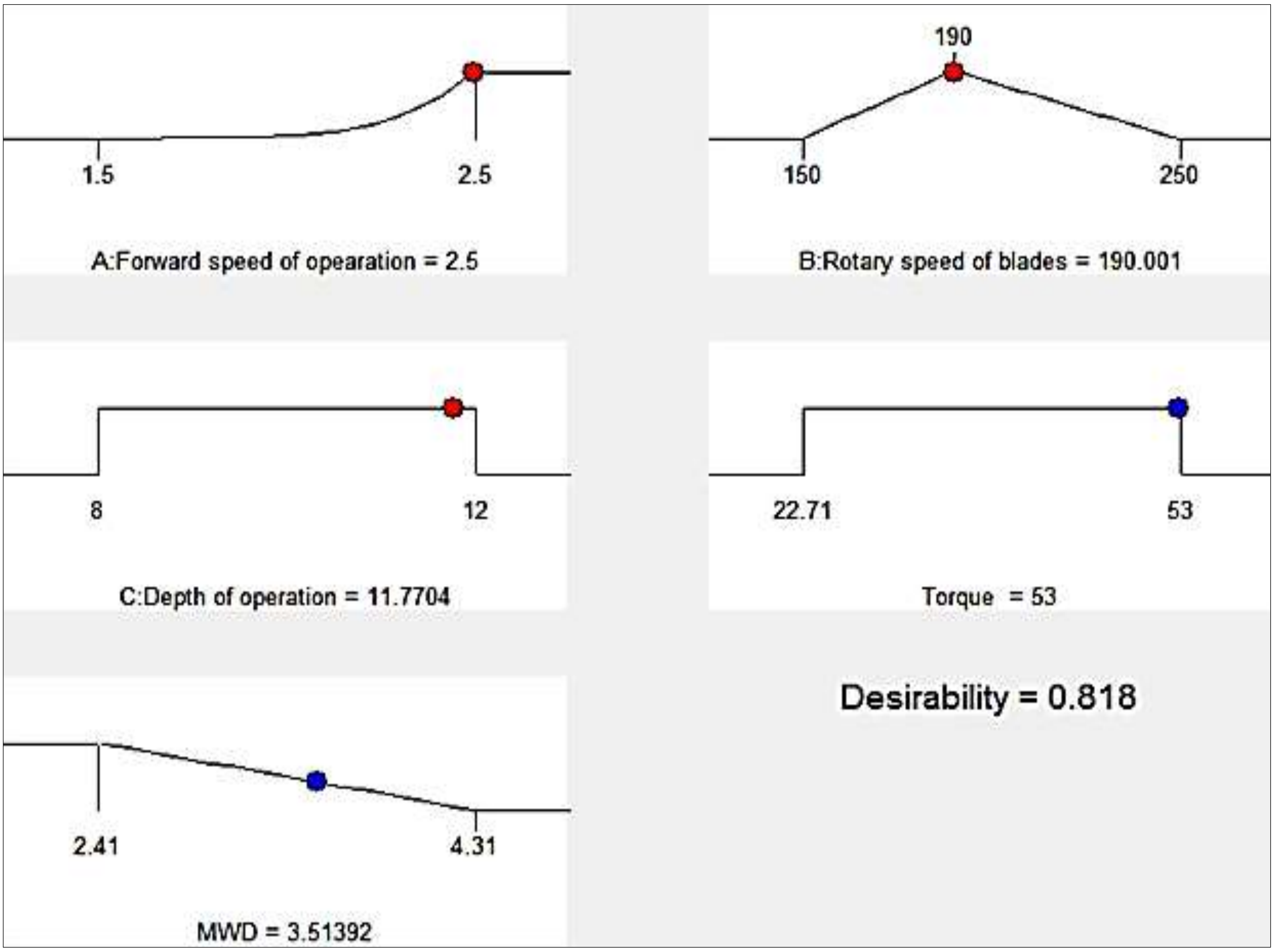


Fig 3: Ramp bar showing set goal for optimizing the performance parameter

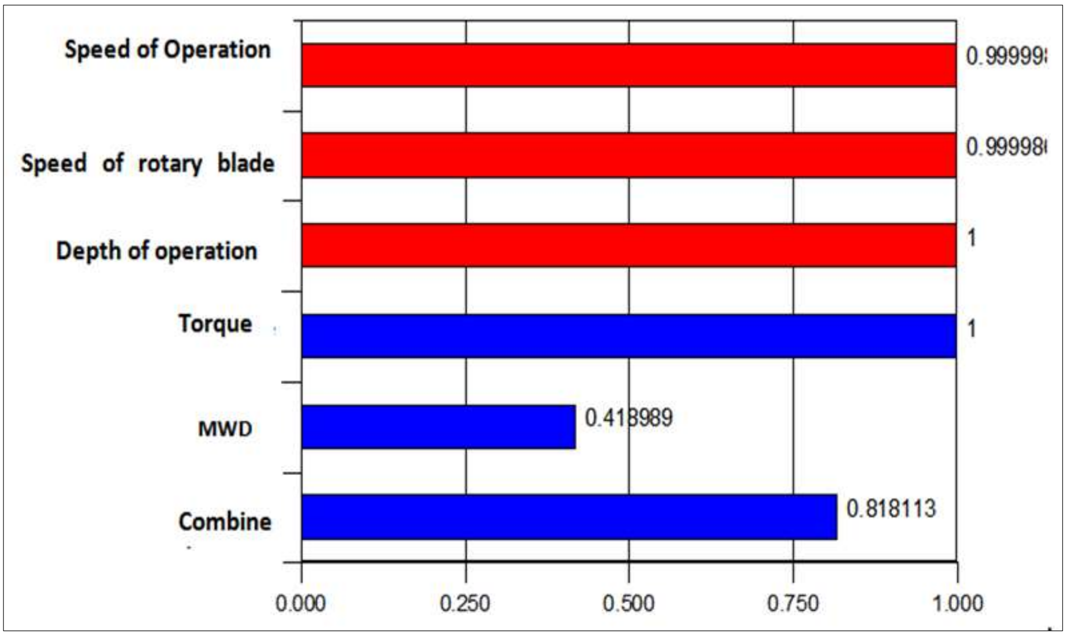


Fig 4: Desirability graph of the different parameter

Conclusion

To develop plastic mulching machine the numerical optimized values for the L-shaped rotary blade were found to be 190 rpm rotary speed, 2.5 km/h forward speed, and 11.7 cm depth of operation respectively whereas corresponding predicted values of the responses, torque 53 Nm, MWD 3.5 mm respectively. The mean value of the observed torque and MWD was found 52.34 Nm and 3.49 mm against predicted mean value values of 52.60 Nm and 3.53 mm in between the range of 95% confidence interval. The L-shaped rotary blade with the above optimized performance can be used for the plastic mulching machine to achieve reduction in tearing of plastic mulch while laying in vertisol condition.

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