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Research Article

OPTIMIZATION OF WEEDING UNIT PERFORMANCE OF MANUALLY OPERATED CONO-WEEDER USING RESPONSE SURFACE METHODOLOGY

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Abstract- The objective of the study was to optimize weeding unit of manually operated cono-weeder for weeding operation in rice crop using response surface methodology and to verify the optimum levels of the variables. The variables considered in the study consisted of diameter of weeding drum and blade angle. Rice seedlings were manually transplanted at 25 x25 cm plant to plant and row to row distance in the field plot of MRRS, AAU, Nawagam. The experiment was divided into two parts one for serrated bladed weeding units and other for plain bladed weeding units. The experiment design was centre composite design in RSM. The experiment was conducted to assess the effect of weeding drum diameter and blade angle on various parameters like draft, power, effective field capacity, weeding efficiency, plant damage, number of clogging, soil volume disturbed, performance index and cost of operation. Data obtained were then used to develop functions in polynomial form that allowed the calculations of the optimum level of each independent variable considered in the study. The optimum level of weeding drum diameter and blade angle were decided on the basis of considering performance index and cost of operation as main parameters. Overall, the best performance was found to be in the serrated bladed weeding of 100 mm drum diameter and 29.37° blade angle and in plain bladed weeding unit of 100 mm drum diameter and 30 .29° blade angle.

Keywords- Performance, Cono-weeder, Paddy, Weeding, Response surface methodology

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Introduction

Weeding is tedious, time consuming and laborious operation in rice cultivation. Hand weeding requires higher labour inputs. Power weeders are not accepted by the farmers in India. Design complexity of many working parts, higher weight and operational instability in puddle field has been identified major drawback of power weeders. Manually operated cono-weeder was developed by IRRI, Philippines and it was modified by Tamil Nadu Agricultural University to make it suitable to Indian agricultural condition. TNAU modified cono-weeder is largely adopted by Indian framers. It facilitates aeration to the root zone results in higher tillering and more yield. An experiment was conducted at Main Rice Research Station, Anand Agricultural University, Nawagam in SRI weeding methods. They revealed that higher yield (4884 kg ha-1) and straw yield (6115 kg ha-1) was observed in cono-weeder weeded plots than hand weeded plot. They also reported that cono-weeder was found drudgerious with frequent clogging of weeding units during operation [1]. Another experiment was conducted in clayey soil condition of Bhal region of Gujarat for the duration of three years at farmers' field. The study was conducted to assess manually operated weeding tools i.e. Japanese paddy weeder, TNAU conoweeder and manual hand weeder "Khurpi". They reported that TNAU cono-weeder was found better than Japanese paddy weeder and Khurpi with higher filed capacity (0.016 ha h-1) but TNAU cono-weeder was found more drudgerious with frequent clogging of weeding units during operation [2].

A considerable effort has been made in developing alternatives to traditional weeding technologies in all over the world [3]. Many different weeders have been designed, selected or proposed with no clear definition of salient characteristics and no definitive design. More than 15 different designs of hoes and weeders are available for rice farming in India. All these designs were developed to meet the requirements of particular soil type, crop grown, cropping pattern and availability of local resources [4]. Hence, a study was conducted to optimize diameter of weeding drum and blade angle for serrated bladed and plain bladed weeding units of the developed cono-weeder for weeding operation in rice crop using response surface methodology. The objective of this study was to optimize the performance of serrated bladed and plain bladed weeding units of the cono-weeder using response surface methodology and to verify the optimum level of variables considered in the study. Numbers of experiments in the past have been conducted to determine the performance of the manually operated weeders and to study the different design parameters of for the development of manually operated weeders for rice crop. Different mechanical weeders were studied and remarked that the weeders are designed to cut the soil beneath weeds with superficial root system or to cut through the roots of weeds with deep root system. He reported that attack angle of 15° is ideal to lift and separate the weeds from the soil and at greater angle; the tyne starts to act like as bulldozer, which tends to leave weeds mixed with soil [5]. The effect of attack angle of weeder tynes were studied and asserted that the attack angle of affects eases of scouring of soil. They reported that reducing the attack angle of tyne, normal force acting on it was reduced and reducing frictional component and consequently the scouring resistance. In another study, they also revealed that attack angle of weeder tynes affects the draft force needed to move the tynes through the soil and reported that draft force increased slowly for angle in the range of 10°-50° and draft force increased more rapidly at larger angle [6]. It was reported that draft requirement of tillage implements depends on soil type and condition, manner of tool's movement and tool shape [7]. Four basic shape of weeding tools attached with animal drawn weeder were studied and reported critical dimensions of the tools based on minimum draft force required per unit working width at laboratory and field condition as below: Straight blade: rake angle 20.6° – 22.5°, blade width 15-50 mm, blade angle 15° or less and thickness as small as possible considering mechanical strength. Curved blade: working width 200 mm, radius of curvature 136.4 mm and rake angle 21.6° - 21.9° and sweeps: approach angle 74.7° - 75°, wing width 50 mm or less and blade thickness less than 4 mm [8]. Literature related to application of response surface methodology to agricultural machinery is very limited. One example was the study conducted on performance evaluation of onion-peeling machine using response surface methodology and concluded that the air pressure, the feeding chain speed and the interaction of onion shape and feeding chain speed are highly significant for both models of peeling efficiency and machine peeling loss [9]. Another example was the study conducted on development of vertical tillage implement and evaluation of the performance of the implement using response surface methodology. From the results of the experimental study, it was concluded that the gang angle, forward speed and depth of operation found with mean mass diameter, draft, fuel consumption, wheel slip and effective field capacity obtained during experiments as 12.28 cm, 106.12 kgf, 11.65 l ha-1, 7.27 % and 0.178 ha h-1 respectively [10].

MaterialsandMethods

Design of experiment:

The rice seedlings were manually transplanted at 25 x 25 cm plant to plant and row to row distance at Main Rice Research Station, Anand Agricultural University, Nawagam (Gujarat). Weeding operation was carried out four times starting from 10th day after transplanting as per SRI guideline. Response surface methodology emphasizes the modeling and analysis of the problem in which response of interest is influenced by several variables and the objective is to optimize this response. It is less laborious and time consuming than other approaches and it is an effective technique for optimizing complex processes since it reduces the number of experiments needed to evaluate multiple parameters and their interactions [11]. Five level, two factor centre composite design (CCD) was employed. The independent variables selected for the experiments were: diameter of weeding drum (X1): 40 mm, 55 mm, 70 mm, 85 mm, 100 mm. and Blade angle (X2) were: 0°, 15°, 30°,45°, 60°. The experiments were carried out for development of serrated and plain bladed weeding units of the developed cono-weeder. The experiment designs of coded and un-coded levels are given in [Table-1] and [Table-2].

Table-1 *Coded and un-coded levels of centre composite design for serrated bladed and plain bladed weeding unit*

Sr. No.	Coded variables		Un-coded variables	
	X1	X2	X1 Diameter of weeding drum (mm)	X2 Blade angle (degree)
1	-1	-1	55	15
2	+1	-1	85	15
3	-1	+1	55	45
4	+1	+1	85	45
5	-2	0	40	30
6	2	0	100	30
7	0	-2	70	0
8	0	+2	70	60
9	0	0	70	30
10	0	0	70	30
11	0	0	70	30
12	0	0	70	30
13	0	0	70	30

Table-2 *Experimental design in coded form for response surface method*

Coded variables		Combinations	Replications	No. of Expt.
X_1	X_2			
±1	±1	4	1	4
±2	0	2	1	2
0	±2	2	1	2
0	0	1	5	5

Note: Code "0" for the centre point of the parameter range investigated, ±1 and ±2 for axial points, X1- diameter of weeding drum (mm) and X2-blade angle (degree)

The response surface problem usually centers on an interest in some response Y, which is a function of k independent variables x1, x2…xk, that is

$$Y = f(x1, x2 \ldots xk)$$

And response surface can take the different forms according to the function types of response. Usually, response function is defined in the quadratic polynomial form as follows:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta iXi + \sum \beta iiXi^2 + \sum \beta ijXiXj + e \qquad \text{[Eq-1]}$$

Where, Y is the response, β0 is the intercept, βi, βii, βij are the coded variables, e is the error

The coding of independent variables into Xi is expressed by the following equation

$$Xi = \frac{X1 - X*}{ds} \qquad \text{[Eq-2]}$$

Where, Xi is the actual value in original units, X* is the mean value (centre point), ds is the step value

Experimental details

The experiment were conducted on net plot size 1.25 m x 25 m of 13 plots for serrated bladed weeding units and 13 plots for pain bladed weeding units [Fig-1] and [Fig-2].

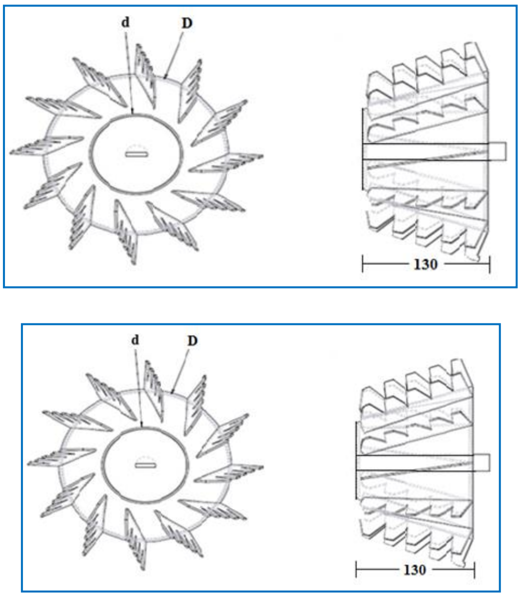


Fig-1 CAD view of serrated bladed and plain bladed weeding units

Fig-2 Developed models of serrated bladed and plain bladed weeding units

The effect of independent parameters like diameter of weeding drum and blade angle were studied on different dependent parameters like draft, power, effective field capacity, weeding efficiency, plant damage, number of clogging, soil volume disturbed, performance index and cost of operation as per standard procedure.

Results and Discussion

The experimental results obtained from the experiments conducted in the field for serrated bladed and plain bladed weeding units are given in [Table-3] and [Table-4]. To analyze the data, Design Expert Software (Statease 8.0) was used to correlate the variation of response with independent variables, a complete second order model [Eq-2] was tested for adequacy. To aid visualization of variation in responses with respect to dependent variables; series of three dimensional response surfaces were drawn. The effect of different independent variables on each dependent parameter is discussed below:

Effect of different parameters on draft requirement:

Draft requirement of the developed equipment with serrated blade ranged from 12.48 kgf to 28.08 kgf with an average value of 21.12 kgf. The minimum draft required by the equipment at combination point (100 mm, 30°), which was about 55.56 % lower than the maximum draft required at combination point (40 mm, 30°). The adequate precision value of 15.52 indicates that the model can be used to predict the response within the design space.

Draft model for serrated bladed equipment in terms of un-coded factors is as below:

Draft $= 48.39 - 0.37X_1 - 0.38 X_2 + 0.0017X_1X_2 + 4.18 \times 10^{-4} X_1^2 + 0.0038X_2^2$

Draft model for serrated bladed equipment in terms of coded factor is as below:

Draft $= 20.22 - 3.9X_1 - 0.39X_2 + 0.39X_1X_2 + 0.094 X_1^2 + 0.87 X_2^2$

Table-3 *Data input values of serrated bladed weeding unit used for analysis*

	Independent variables		Dependent variables								
Run	Factor-1 X_1 Diameter of weeding drum (mm)	Factor-2 X_2 Blade angle (degree)	Response-1 Y_1 Draft (kgf)	Response-2 Y_2 Power (hp)	Response-3 Y_3 Effective field capacity (ha h^{-1})	Response-4 Y_4 Weeding efficiency (%)	Response-5 Y_5 Plant damage (%)	Response-6 Y_6 Numbers of clogging	Response-7 Y_7 Soil volume disturbed (m^3 h^{-1})	Response-8 Y_8 Performance index	Response-9 Y_9 Cost of operation (₹ ha^{-1})
1	40	30	28.08	0.105	0.018	81.43	12.50	5.67	4.50	1223.39	1596.00
2	70	30	22.62	0.097	0.021	83.16	10.00	4.00	5.23	1596.72	1373.07
3	100	30	12.48	0.085	0.035	90.48	6.25	3.00	8.75	3451.39	820.80
4	70	30	18.72	0.098	0.026	86.14	8.75	4.00	6.47	2062.55	1109.60
5	70	60	22.62	0.102	0.022	83.87	10.00	4.67	5.54	1622.27	1297.07
6	70	30	21.06	0.097	0.022	83.87	8.75	4.00	5.65	1771.31	1271.73
7	55	45	24.96	0.102	0.020	83.33	10.00	4.67	5.01	1455.73	1433.87
8	85	15	17.94	0.096	0.026	86.67	7.50	4.00	6.62	2202.41	1084.27
9	70	30	18.72	0.098	0.029	83.87	8.75	4.33	7.42	2302.66	967.73
1	70	0	24.18	0.104	0.021	83.16	11.25	5.33	5.23	1472.96	1373.07
11	55	15	26.52	0.104	0.019	81.48	11.25	5.33	4.89	1348.69	1469.33
12	70	30	18.72	0.098	0.026	84.00	8.75	4.00	6.56	2039.28	1094.40
13	85	45	17.94	0.094	0.025	88.00	7.50	3.67	6.39	2198.74	1124.80

Table-4 *Data input values of plain bladed weeding unit used for analysis*

	Independent variables		Dependent variables								
Run	Factor-1 X_1 Diameter of weeding drum (mm)	Factor-2 X_2 Blade angle (degree)	Response-1 Y_1 Draft (kgf)	Response-2 Y_2 Power (hp)	Response-3 Y_3 Effective filed capacity (ha h^{-1})	Response-4 Y_4 Weeding efficiency (%)	Response-5 Y_5 Plant damage (%)	Response-6 Y_6 Numbers of clogging	Response-7 Y_7 Soil volume disturbed (m^3 h^{-1})	Response-8 Y_8 Performanc e index	Response-9 Y_9 Cost of operation (₹ ha^{-1})
1	40	30	28.86	0.106	0.018	81.37	11.25	6.33	4.47	1215.53	1606.13
2	70	30	23.40	0.099	0.020	82.40	8.75	4.67	5.14	1547.14	1398.40
3	100	30	14.04	0.085	0.031	90.91	5.00	3.67	7.70	3102.79	932.27
4	70	30	20.28	0.100	0.024	85.14	7.50	4.67	6.14	1914.78	1170.40
5	70	60	23.40	0.104	0.022	81.94	8.75	5.33	5.43	1549.36	1322.40
6	70	30	22.62	0.099	0.021	83.33	7.50	4.67	5.33	1648.43	1347.73
7	55	45	25.74	0.104	0.020	83.08	6.25	4.33	4.97	1478.07	1444.00
8	85	15	17.94	0.098	0.027	86.67	7.50	4.67	6.78	2209.91	1058.93
9	70	30	21.84	0.100	0.022	83.22	8.75	5.00	5.65	1694.72	1271.73
1	70	0	24.96	0.104	0.020	82.40	10.00	5.67	5.04	1427.42	1423.73
11	55	15	28.08	0.104	0.018	81.75	10.00	5.67	4.54	1275.39	1580.80
12	70	30	23.40	0.101	0.021	83.06	8.75	4.67	5.23	1563.18	1373.07
13	85	45	17.16	0.095	0.028	88.00	6.25	4.33	6.95	2386.17	1033.60

Similarly, the draft requirement of the developed equipment with plain blade ranged from 14.04 kgf to 28.86 kgf with an average value of 22.44 kgf. The minimum draft required by the equipment at combination point (100 mm, 30°) was about 51.35 % lower than the maximum draft required at combination point (40 mm, 30°). The adequate precision value of 19.79 indicates that the model can be used to predict the response within the design space.

Draft model for plain bladed equipment in terms of un-coded factors is as below

Draft= $42.750 – 0.183X_1 – 0.279X_2 + 0.0017\, X_1X_2 – 9.8 \times 10^{-4}\, X_1^2 – 2.05 \times 10^{-3}\, X_2^2$

Draft model for plain bladed equipment in terms of coded factor is as below

Draft = $22.21 – 4.03X_1 – 0.52X_2 + 39X_1X_2 – 0.22\, X_1^2 + 0.46\, X_2^2$

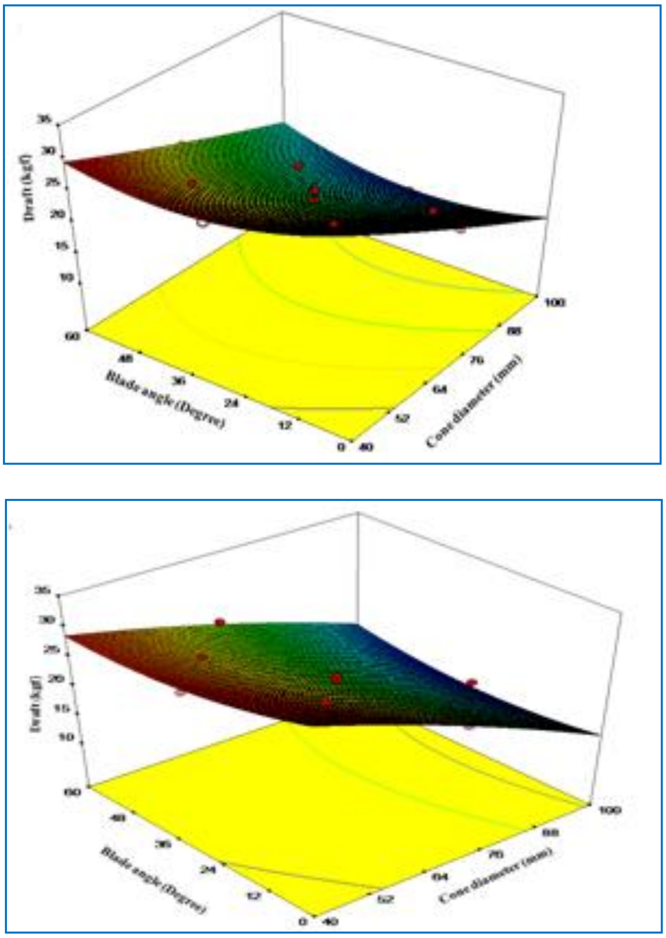


Fig-3 Variation of draft with respect to diameter of weeding drum and blade angle in serrated and plain bladed weeding unit

[Fig-3] indicates that draft decreased with increase in diameter of weeding drum in both serrated and plain bladed weeding units. It can further be observed that draft was initially decreased but, later on, increased with increase in blade angle. The lowest draft 12.48 kgf was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to plain bladed weeding unit. This may be due to the easiness in movement of bigger size cone in comparison to smaller.

Effect of different parameters on power requirement

Power requirement of the developed equipment with serrated blade ranged from 0.085 hp to 0.105 hp with an average value of 0.098 hp. The minimum power required by the equipment at combination point (100 mm, 30°) which was about 18.73 % lower than the maximum power required at combination point (40 mm, 30°). The adequate precision value of 39.04 indicates that the model can be used to predict the response within the design space.

Power model for serrated bladed equipment in terms of un-coded factors as below:

Power = $0.109 + 0.00015\, X_1 – 3.9 \times 10^{-4}\, X_2 – 3.1 \times 10^{-7}\, X_1X_2 – 3.1 \times 10^{-6}\, X_1^2 + 6.2 \times 10^{-6}\, X_2^2$

Power model for serrated bladed equipment in terms of coded factor as below:

Power = $0.097 – 0.0045\, X_1 – 0.00058\, X_2 – 6.9 \times 10^{-5}\, X_1X_2 – 0.0007\, X_1^2 – 0.0014$

Similarly, the power requirement of the developed equipment with plain blade ranged from 0.085 hp to 0.106 hp with an average value of 0.100 hp. The minimum power required by the equipment at combination point (100 mm, 30°) which was about 19.73 % lower than the maximum power required at combination point (40 mm, 30°). The adequate precision value of 24.49 indicates that the model can be used to predict the response within the design space.

Power model for plain bladed equipment in terms of un-coded factors

Power =$0.096 + 4.73 \times 10^{-4}\, X_1 – 1.1 \times 10^{-4}\, X_2 – 2.6 \times 10^{-6}\, X_1X_2 – 5 \times 10^{-6}\, X_1^2 + 4.67 \times 10^{-6}\, X_2^2$

Power model for plain bladed equipment in terms of coded factor

Power = $0.099 – 0.0046X_1 – 0.0002X_2 – 0.0006X_1X_2 – 0.0011\, X_1^2 + 1.05 \times 10^{-3}\, X_2^2$

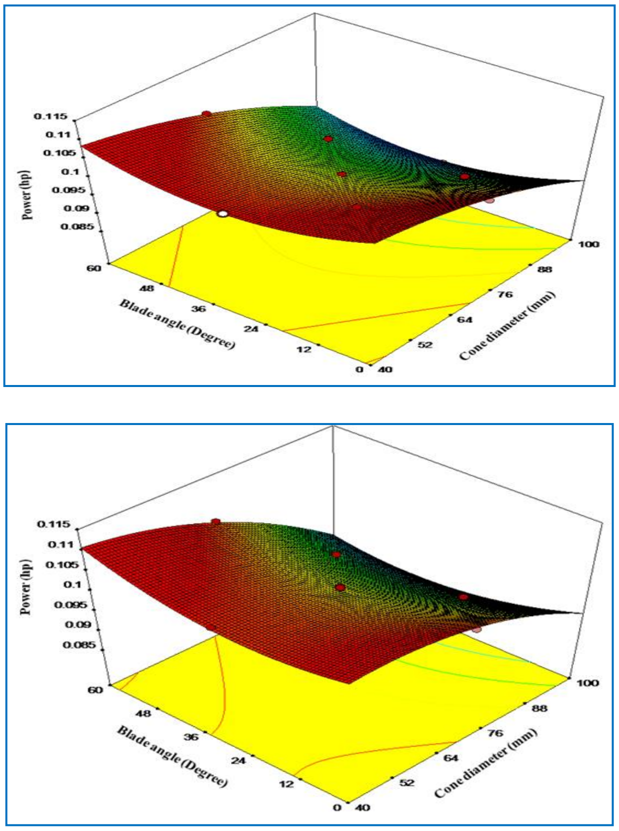


Fig-4 Variation of power with respect to diameter of weeding drum and blade angle in Serrated and plain bladed weeding unit

[Fig-4] indicates that power decreased with diameter of weeding drum and was initially decreased but, later on, increased with blade angle in both the type of weeding units. The lowest power 0.085 hp was observed in serrated bladed and plain bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle. The power required by serrated bladed weeding units was significantly influenced by diameter of weeding drum and blade angle and power required by plain bladed weeding unit was significantly influenced by diameter of weeding drum only. But, their interactions were found non-significant.

Effect of different parameters on effective field capacity

Effective field capacity of the developed equipment with serrated blade ranged from 0.018 ha h^{-1} to 0.035 ha h^{-1} with an average value of 0.024 ha h^{-1}. The maximum effective field capacity observed by the equipment at combination point (100 mm, 30°) which was about 94.44 % higher than the minimum effective field capacity observed at combination point (40 mm, 30°). The adequate precision value of 7.91 indicates that the model can be used to predict the response.

Effective field capacity model for serrated bladed equipment in terms of un-coded factors as below:

Effective field capacity $= 0.0063 + 1.0 \times 10^{-4} X_1 + 3.6 \times 10^{-4} X_2 - 1.6 \times 10^{-6} X_1X_2 + 1.45 \times 10^{-6} X_1^2 - 4 \times 10^{-6} X_2^2$

Effective field capacity model for serrated bladed equipment in terms of coded factor as below:

Effective field capacity $= 0.024 + 0.0038 X_1 + 0.00016 X_2 - 3.6 \times 10^{-4} X_1X_2 + 3.2 \times 10^{-4} X_1^2 - 9 \times 10^{-4} X_2^2$

Similarly, effective field capacity of the developed equipment with plain blade ranged from 0.018 ha h^{-1} to 0.031 ha h^{-1} with an average value of 0.022 ha h^{-1}. The maximum effective field capacity observed by the equipment at combination point (100 mm, 30°) which was about 72.28 % higher than the minimum effective field capacity observed at combination point (40 mm, 30°).The adequate precision value of 14.01 indicates that the model can be used to predict the response within the design space.

Effective field capacity model for plain bladed equipment in terms of un-coded factors

Effective field capacity $= 0.014 - 1 \times 10^{-4}X_1 + 1.7 \times 10^{-4}X_2 - 1.2\times 10^{-6} X_1X_2 + 2.6 \times 10^{-6} X_1^2 - 1.1 \times 10^{-6}X_2^2$

Effective field capacity model for plain bladed equipment in terms of coded factor

Effective field capacity $= 0.022 + 0.0035 X_1 + 0.00045 X_2 - 2.6 \times 10^{-4}X_1X_2 + 6.03 \times 10^{-4} X_1^2 - 2.4 \times 10^{-4} X_2^2$

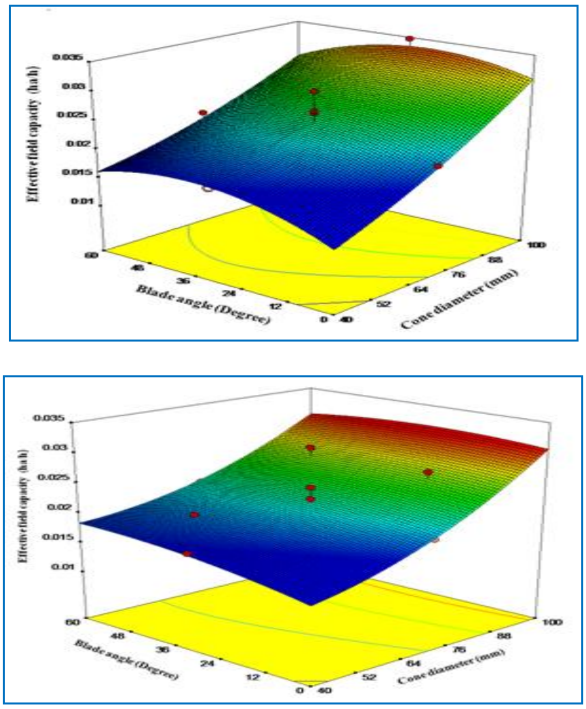


Fig-5 Variation of effective field capacity with respect to diameter of weeding drum and blade angle in serrated and plain bladed weeding unit

[Fig-5] indicates that effective field capacity increased with diameter of weeding drum and it initially, increased but, later on, decreased with blade angle in both the types of weeding unit. The highest effective field capacity 0.035 ha h^{-1} was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to plain bladed weeding unit. The effect of diameter of weeding drum on effective field capacity was found significant. But, the effect of blade angle and their interactions were found non-significant.

Effect of different parameters on weeding efficiency

Weeding efficiency of the developed equipment with serrated blade ranged from 81.43 % to 90.48 %with an average value of 84.57 %. The maximum weeding efficiency observed by the equipment at combination point (100 mm, 30°) which was about 11.10 % higher than the minimum weeding efficiency observed at combination point (40 mm, 30°). The adequate precision value of 14.05 indicates that the model can be used to predict the response within the design space.

Weeding efficiency model for serrated bladed equipment in terms of un-coded factors as below:

Weeding efficiency $= 80.44 - 0.103X_1 + 0.11X_2 - 0.0005X_1X_2 + 0.0019X_1^2 - 0.00074X_2^2$

Weeding efficiency model for serrated bladed equipment in terms of coded factor as below:

Weeding efficiency $= 84.31 + 2.32 X_1 + 0.38 X_2 - 0.13X_1X_2 + 0.44X_1^2 - 0.16X_2^2$

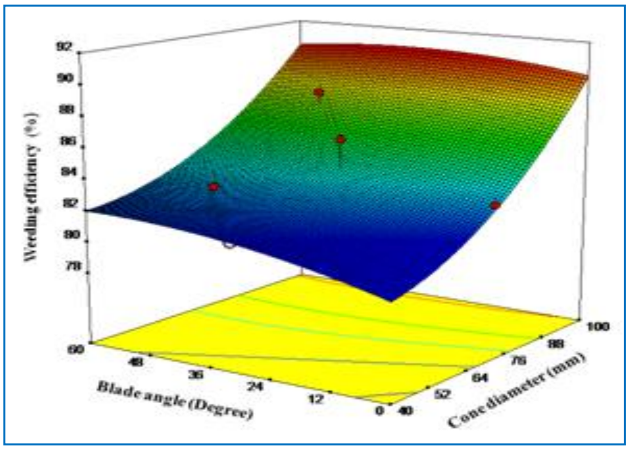
Similarly, weeding efficiency of the developed equipment with plain blade ranged from 81.37 % to 90.91 % with an average value of 84.10 %. The maximum weeding efficiency observed by the equipment at combination point (100 mm,30°) which was about 11.72 % higher than the minimum weeding efficiency observed at combination point (40 mm, 30°). The adequate precision value of 12.65 indicates that the model can be used to predict the response within the design space.

Weeding efficiency model for plain bladed equipment in terms of un-coded factors as below

Weeding efficiency $= 86.17 - 0.27X_1 + 0.088X_2 + 2.7\times10^{-6} X_1X_2 + 0.003X_1^2 - 0.00132X_2^2$

Weeding efficiency model for plain bladed equipment in terms of coded factor as below

Weeding efficiency $= 83.72 + 2.40X_1 + 0.14X_2 - 6.11 \times 10^{-4} X_1X_2 + 0.69X_1^2 - 0.29X_2^2$



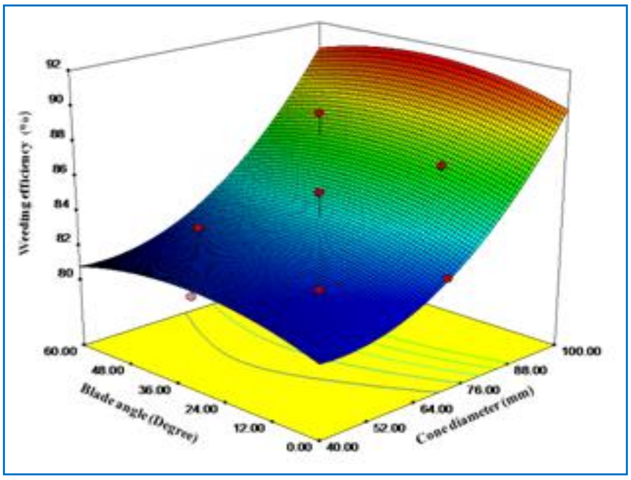


Fig-6 Variation of weeding efficiency with respect to diameter of weeding drum and blade angle in serrated and plain bladed weeding unit

[Fig-6] indicates that weeding efficiency decreased initially but, later on, increased with diameter of weeding drum in both the types of weeding unit. Weeding efficiency was initially increased but, later on, decreased with blade angle. The highest weeding efficiency 90.91% was observed in plain bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to serrated bladed weeding unit. The effect of diameter of weeding drum on weeding efficiency was found significant. But, the effect of blade angle and their interactions were found non-significant.

Effect of different parameters on plant damage

Plant damage of the developed equipment with serrated blade ranged from 6.25 % to 12.50 % with an average value of 9.33 %. The minimum plant damage observed by the equipment at combination point (100 mm, 30°) which was about 50 % lower than the maximum plant damage observed at combination point (40 mm, 30°). The adequate precision value of 18.25 indicates that the model can be used to predict the response within the design space.

Plant damage model for serrated bladed equipment in terms of un-coded factors

Plant damage = $23.18 - 0.19 X_1 - 0.22X_2 + 0.0014X_1X_2 + 0.00038X_1^2 + 0.0017X_2^2$

Plant damage model for serrated bladed equipment in terms of coded factor

Plant damage = $8.87-1.56X_1- 0.31X_2+ 0.086X_1^2+0.39X_2^2$

Similarly, plant damage of the developed equipment with plain blade ranged from 5 % to 11.25 % with an average value of 8.17 %. The minimum plant damage observed by the equipment at combination point (100 mm, 30°) which was about 55.56 % lower than the maximum plant damage observed at combination point (40 mm, 30°). The adequate precision value of 6.90 indicates that the model can be used to predict the response within the design space.

Plant damage model for plain bladed equipment in terms of un-coded factors as below:

Plant damage = $20.89- 0.13X_1- 0.30X_2 + 0.0027X_1X_2 - 0.0002X_1^2 + 0.0011X_2^2$

Plant damage f model for plain bladed equipment in terms of coded factor as below:

Plant damage = $7.97 - 1.25X_1 - 0.625 X_2+ 0.625X_1X_2 - 0.048X_1^2+ 0.26X_2^2$

[Fig-7] indicates that that plant damage decreased with diameter of weeding drum and initially decreased, but, later on, increased with blade angle in both the types of the weeding unit. The minimum plant damage 5 % was observed in plain bladed weeding units of 100 mm diameter of weeding drum and 30° blade angle in comparison to serrated bladed weeding unit.

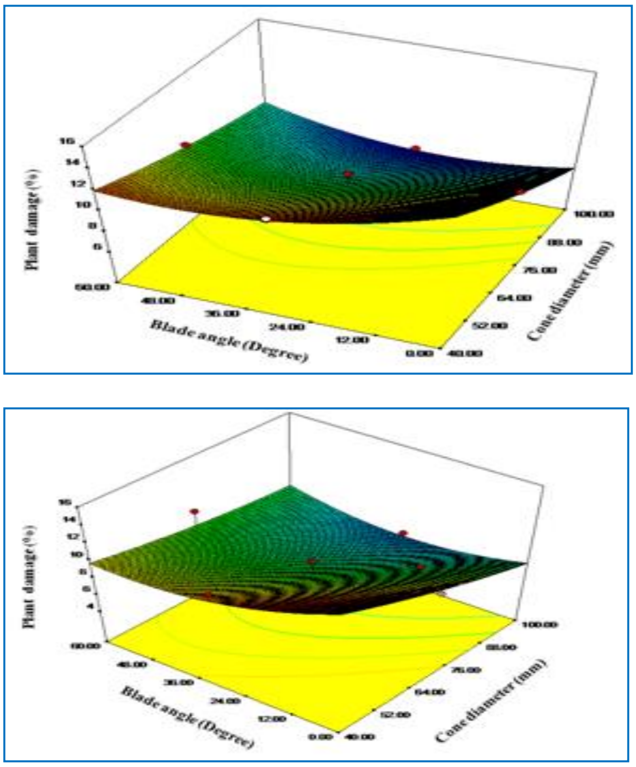


Fig-7 Variation of plant damage percent with respect to diameter of weeding drum and blade angle in plain bladed weeding unit

Effect of different parameters on number of clogging

Number of clogging observed in 20 m run of the developed equipment with serrated blade ranged from 3 to 5.67 with an average value of 4.36. The minimum number of clogging observed by the equipment at combination point (100 mm,30°) which was about 47.06 % lower than the maximum numbers of clogging observed at combination point (40 mm, 30°). The adequate precision value of 27.30 indicates that the model can be used to predict the response within the design space.

Number of clogging model for serrated bladed equipment in terms of un-coded factors as below:

Number of clogging = $10.63 - 0.095X_1 - 0.101X_2 + 0.00037 X_1X_2 + 0.0003X_1^2 + 0.0010X_2^2$

Number of clogging model for serrated bladed equipment in terms of coded factor as below:

Number of clogging = $4.08 - 0.63X_1 - 0.19X_2 + 0.083 X_1X_2 + 0.067X_1^2 + 0.23X_2^2$

Similarly, number of clogging observed in 20 m run of the developed equipment with plain blade ranged from 3.67 to 6.33 with an average value of 4.90. The minimum number of clogging observed by the equipment at combination point (100 mm, 30°) which was about 42.11 % lower than the maximum numbers of clogging observed at combination point (40 mm, 30°). The adequate precision value of 8.18 indicates that the model can be used to predict the response within the design space.

Number of clogging model for plain bladed equipment in terms of un-coded factors as below:

Number of clogging= $11.96 - 0.107X_1 - 0.14 X_2 + 0.0011X_1X_2 + 2.7 \times 10^{-4}X_1^2 + 8.3 \times 10^{-4} X_2^2$

Number of clogging model for plain bladed equipment in terms of coded factor as below:

Number of clogging= $4.66 - 0.52X_1 - 0.19X_2 + 0.25X_1X_2 + 0.062X_1^2 + 0.18X_2^2$

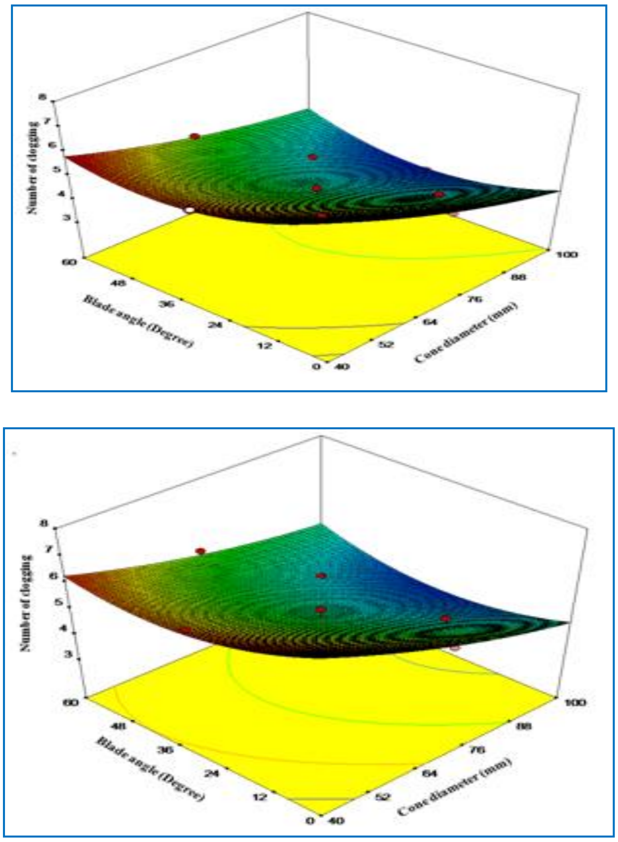


Fig-8 Variation of clogging with respect to diameter of weeding drum and blade angle in serrated and plain bladed weeding unit

[Fig-8] indicates that number of clogging decreased with diameter of weeding drum in both the types of weeding units. Number of clogging was initially decreased but, later on, increased with blade angle also. The minimum number of clogging 3 was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to plain bladed weeding unit. The clogging created by serrated bladed weeding units was significantly influenced by diameter of weeding drum and blade angle and clogging created by plain bladed weeding unit was significantly influenced by diameter of weeding drum only. But, their interactions were found non-significant.

Effect of different parameters on soil volume disturbed

Soil volume disturbed by the developed equipment with serrated blade ranged from 4.50 m^3h^{-1} to 8.75 m^3h^{-1} with an average value of 6.02 m^3h^{-1}. The maximum soil volume disturbed observed by the equipment at combination point (100 mm,30°) which was about 94.44 % higher than the minimum soil volume disturb observed at combination point (40 mm, 30°).The adequate precision value of 7.9 indicates that the model can be used to predict the response within the design space.

Soil volume disturbed model for serrated bladed equipment in terms of un-coded factors as below:

Soil volume disturbed = $1.60 + 0.025X_1 + 0.091X_2 - 4 \times 10^{-4}X_1X_2 + 0.00036X_1^2 - 0.001X_2^2$

Soil volume disturb model for serrated bladed equipment in terms of coded factor as below:

Soil volume disturb = $6.15 + 0.96X_1 + 0.041X_2 - 0.089X_1X_2 + 0.082X_1^2 - 0.22X_2^2$

Similarly, soil volume disturbed by the developed equipment with plain blade ranged from 4.47 m^3h^{-1} to 7.70 m^3h^{-1} with an average value of 5.64 m^3h^{-1}. The maximum soil volume disturbed observed by the equipment at combination point (100 mm, 30°) which was about 72.28 % higher than the minimum soil volume disturb observed at combination point (40 mm, 30°). The adequate precision value of 14.01 indicates that the model can be used to predict the response within the design space.

Soil volume disturbed model for plain bladed equipment in terms of un-coded factors as below

Soil volume disturbed = $3.63 - 0.026X_1 + 0.044X_2 - 2.9 \times 10^{-4}X_1X_2 + 6.7 \times 10^{-4}X_1^2 - 2.7 \times 10^{-4}X_2^2$

Soil volume disturbed model for plain bladed equipment in terms of coded factor as below

Soil volume disturbed = $5.56 + 0.88X_1 + 0.11X_2 - 0.066X_1X_2 + 0.15X_1^2 - 0.06X_2^2$

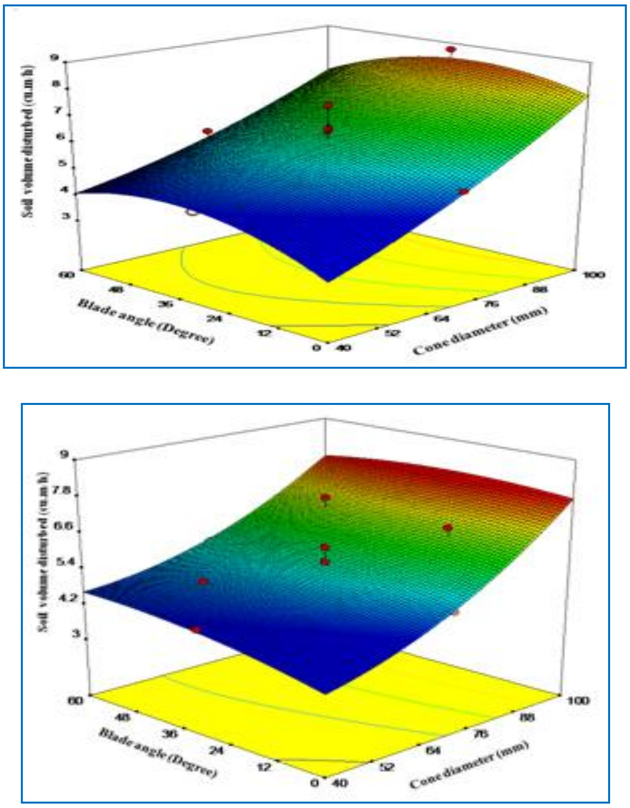


Fig-9 Variation of soil volume disturbed with respect to diameter of weeding drum and blade angle in serrated and plain bladed weeding unit

[Fig-9] indicates that that the soil volume disturbed increased with diameter of weeding drum and initially, it increased but, later on, decreased with blade angle in both types of the weeding units. The highest soil volume disturbed of 8.75 $m^3 h^{-1}$ was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to plain bladed weeding unit.

Effect of different parameters on performance index

Performance index calculated of the developed equipment with serrated blade ranged from 1223.39 to 3451.39 with an average value of 1903.70. The maximum performance index found by the equipment at combination point (100 mm, 30°) which was about 182.12 % higher than the minimum performance index found at combination point (40 mm, 30°).The adequate precision value of 12.57 indicates that the model can be used to predict the response within the design space.

Performance index model for serrated bladed equipment in terms of un-coded factors as below

Performance index = $1017.88 - 24.23X1 + 34.40X2 - 0.09X1X2 + 0.433X12- 0.432X22$

Performance index model for serrated bladed equipment in terms of coded factor as below

Performance index = $1900.81 + 506X1 + 32.51X2 - 20.25X1X2 + 97.59X12- 97.25X22$

Similarly, performance index calculated of the developed equipment with plain blade ranged from 1215.53 to 3102.79 with an average value of 1770.22. The maximum performance index found by the equipment at combination point (100 mm, 30°) which was about 155.26 % higher than the minimum performance index found at combination point (40 mm, 30°). The adequate precision value of 20.51 indicates that the model can be used to predict the response within the design space.

Performance index model for plain bladed equipment in terms of un-coded factors as below:

Performance index = $1878.06 - 43.28X1+12.80X2 + 0.016X1X2 + 0.52X12- 0.18X22$

Performance index model for plain bladed equipment in terms of coded factor as below:

Performance index = $1696.53 + 469.7X1 + 45.47X2 + 3.73X1X2 + 119.09X12 - 41.01X22$

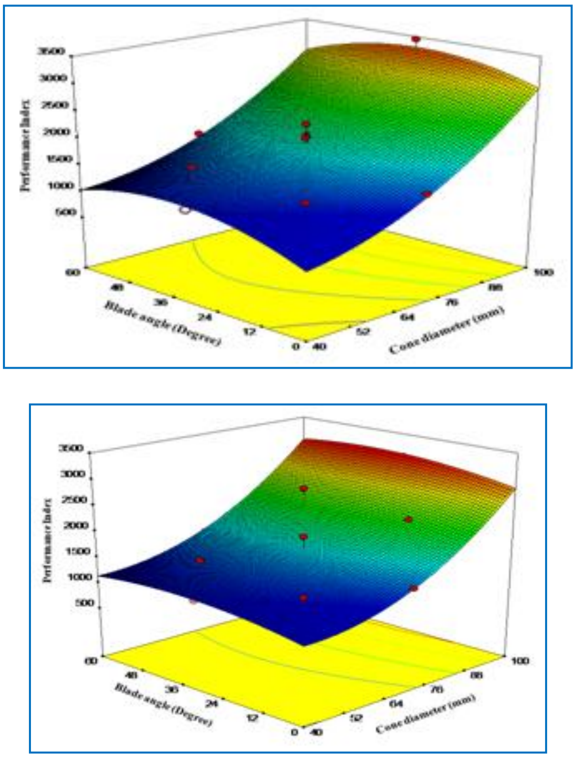


Fig-10 Variation of performance index with respect to diameter of weeding drum and blade angle in serrated and plain bladed weeding unit

[Fig-10] indicates that performance index decreased initially but, later on, increased with diameter of weeding drum and it increased initially, but, later on, decreased with blade angle in both the types of weeding unit. The maximum performance index 3451.39 was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to plain bladed weeding unit. The effect of diameter of weeding drum on performance index was found significant. But, the effect of blade angle and their interactions were found non-significant.

Effect of different parameters on cost of operation

Cost of operation calculated of the developed equipment with serrated blade ranged from 820.80 ₹ha^{-1} to 1596 ₹ ha^{-1} with an average value of 1232 ₹ ha^{-1}. The minimum cost of operation found of the equipment at combination point (100 mm,30°) which was about 48.57 % lower than the maximum cost of operation found at combination point (40 mm, 30°).The adequate precision value of 8.63 indicates that the model can be used to predict the response within the design space.

Cost of operation model for serrated bladed equipment in terms of un-coded factors as below

Cost of operation = $2698.88 - 22.66X_1 - 18.45X_2 + 0.084 X_1 X_2 + 0.054X_1^2 + 0.19 X_2^2$

Cost of operation model for serrated bladed equipment in terms of coded factor as below

Cost of operation = $1180 - 187.04X_1 - 12.24X_2 + 19 X_1 X_2 + 12.31X_1^2 + 43.98X_2^2$

Similarly, cost of operation calculated of the developed equipment with plain blade ranged from 932.27 ₹ ha^{-1} to 1606.13 ₹ ha^{-1} with an average value of 1304.86 ₹ha^{-1}. The minimum cost of operation found of the equipment at combination point (100 mm,30°) which was about 41.96 % lower than the maximum cost of operation found at combination point (40 mm, 30°). The adequate precision value of 13.27 indicates that the model can be used to predict the response within the design space.

Cost of operation model for plain bladed equipment in terms of un-coded factors

Cost of operation = $2319.23 - 9.28X_1 - 14.57X_2 + 0.123X_1X_2 - 0.05X_1^2 + 0.064X_2^2$

Cost of operation model for plain bladed equipment in terms of coded factor

Cost of operation =$1301.95- 190X_1 -30.4X_2+ 27.86X_1X_2- 11.41X_1^2 + 14.55X_2^2$

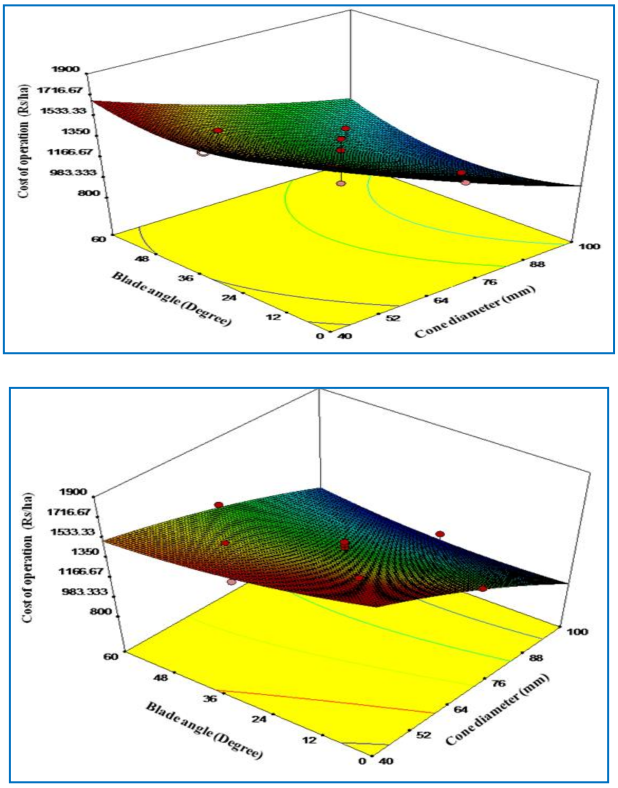


Fig-11 Variation of cost of operation with respect to diameter of weeding drum and blade angle in serrated and plain bladed weeding unit

[Fig-11] indicated that cost of operation decreased with diameter of weeding drum and it decreased initially, but, later on, increased with blade angle in both the types of weeding units. The minimum cost of operation 820.80 was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to plain bladed weeding unit. The effect of diameter of weeding drum on cost of operation was found significant. But, the effect of blade angle and their interactions were found non-significant.

Optimization of serrated bladed and plain bladed weeding units:

The optimization with different independent and dependent parameters was carried out using manual regression quadratic model with the help of software "Design Expert 8.0". The data of serrated bladed weeding units and plain bladed weeding units were optimized as per the performance index and cost of operation for overall best results for different cone diameters and blade angles. The values of overall best results for serrated bladed weeding unit are shown in [Table-5]. It is clear from the table that at 100 mm cone diameter and 29.37° blade angle, the performance index was maximum with the value of 3305.12 and cost of operation was minimum with the value of 850.19 ₹ ha^{-1}. Similarly, the values of overall best results for plain bladed weeding unit are shown in [Table-6]. It is clear from the table that at 100 mm cone diameter and 30.29° blade angle, the performance index was maximum with the value of 3113.36 and cost of operation was minimum with the value of 873.81 ₹ ha^{-1}.

Table-5 *Optimized overall best results of the serrated bladed weeding unit*

Diameter of weeding drum (mm)	Blade angle (degree)	Draft (kgf)	Power (hp)	Effective field capacity (ha h^{-1})	Weeding efficiency (%)	Plant damage (%)	Number of Clogging	Soil volume disturbed (m^3 h^{-1})	Performance index	Cost of operation (₹ ha^{-1})
100	**29.37**	**12.78**	**0.086**	**0.033**	**90.74**	**5.71**	**3.07**	**8.42**	**3305.12**	**850.19**
100	28.60	12.77	0.086	0.033	90.76	5.72	3.07	8.43	3304.86	853.16
100	28.63	12.77	0.086	0.033	90.73	5.72	3.07	8.43	3304.88	853.21
100	28.54	12.77	0.086	0.033	90.73	5.72	3.07	8.43	3304.81	853.09
100	28.72	12.77	0.086	0.033	90.73	5.72	3.07	8.42	3304.93	853.32
100	28.46	12.77	0.086	0.033	90.73	5.72	3.07	8.43	3304.75	853.01
100	28.45	12.77	0.086	0.033	90.73	5.73	3.07	8.43	3304.74	853.00
100	28.92	12.77	0.086	0.033	90.74	5.72	3.07	8.42	3305.02	853.57
100	28.17	12.76	0.086	0.033	90.73	5.73	3.08	8.43	3304.48	852.71
100	28.03	12.76	0.086	0.033	90.73	5.73	3.08	8.43	3304.33	852.57
100	26.62	12.75	0.086	0.033	90.71	5.75	3.09	8.43	3301.82	851.62
100	26.56	12.75	0.086	0.033	90.71	5.75	3.09	8.43	3301.68	851.59
100	26.48	12.75	0.086	0.033	90.71	5.75	3.09	8.43	3301.47	851.56
100	25.82	12.76	0.086	0.033	90.70	5.76	3.09	8.44	3299.63	851.42
100	25.50	12.76	0.086	0.033	90.69	5.77	3.10	8.44	3298.59	851.42

Table-6 *Optimized overall best result of plain bladed weeding unit*

Diameter of weeding drum (mm)	Blade angle (degree)	Draft (kgf)	Power (hp)	Effective field capacity (ha h^{-1})	Weeding efficiency (%)	Plant damage (%)	Number of Clogging	Soil volume disturbed (m^3 h^{-1})	Performance index	Cost of operation (₹ ha^{-1})
100	**30.29**	**13.28**	**0.086**	**0.032**	**91.33**	**5.44**	**3.86**	**7.94**	**3113.36**	**873.81**
100	29.37	13.26	0.086	0.032	91.32	5.45	3.84	7.94	3110.07	875.29
100	29.09	13.26	0.086	0.032	91.32	5.45	3.84	7.94	3109.01	874.84
100	29.02	13.26	0.086	0.032	91.32	5.45	3.84	7.94	3108.72	874.72
100	29.15	13.26	0.086	0.032	91.32	5.45	3.84	7.94	3109.23	874.93
100	29.17	13.26	0.086	0.032	91.32	5.45	3.84	7.94	3109.29	874.96
100	28.94	13.26	0.086	0.032	91.32	5.46	3.84	7.94	3108.42	874.61
100	29.23	13.26	0.086	0.032	91.32	5.45	3.84	7.94	3109.54	875.06
100	28.88	13.25	0.086	0.032	91.32	5.46	3.83	7.94	3108.17	874.50
100	28.82	13.25	0.086	0.032	91.32	5.46	3.83	7.94	3107.94	874.42

Conclusions

Response surface methodology is a very effective tool and provides a means of optimizing the performance of serrated bladed and plain bladed weeding units of the developed cono-weeder. The response models may be used for estimating the performance related variables such as draft, power, effective field capacity, weeding efficiency, plant damage, number of clogging, soil volume disturbed, performance index and cost of operation.

Base on the present study, the following conclusions may be drawn:

1. The lowest draft 12.48 kgf was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to plain bladed weeding unit. The effect of diameter of weeding drum on draft was found significant but, the effect of blade angle and their interactions were found non-significant.
2. The lowest power 0.085 hp was observed in serrated bladed and plain bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle. The power required by serrated bladed weeding units was significantly influenced by diameter of weeding drum and blade angle and power required by plain bladed weeding unit was significantly influenced by diameter of weeding drum only. But, their interactions were found non-significant.
3. The highest effective field capacity 0.035 ha h^{-1} was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to plain bladed weeding unit. The effect of diameter of weeding drum on effective field capacity was found significant. But, the effect of blade angle and their interactions were found non-significant.
4. The highest weeding efficiency 90.91% was observed in plain bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to serrated bladed weeding unit. The effect of diameter of weeding drum on weeding efficiency was found significant. But, the effect of blade angle and their interactions were found non-significant.
5. The minimum plant damage 5% was observed in plain bladed weeding unit of 100 mm diameter of weeding drum and 30° blade angle in comparison to serrated bladed weeding unit. The effect of diameter of weeding drum on plant damage was found significant. But, the effect of blade angle and their interaction was found non-significant.
6. The clogging created by serrated bladed weeding units was significantly influenced by diameter of weeding drum and blade angle and clogging created by plain bladed weeding unit was significantly influenced by diameter of weeding drum only. But, their interactions were found non-significant.

7. The maximum soil volume disturbed 8.75 m^3h^{-1} was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30°blade angle in comparison to plain bladed weeding unit. The effect of diameter of weeding drum on soil volume disturbed was found significant. But, the effect of blade angle and their interactions were found non-significant.
8. The maximum performance index 3451.39 was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30°blade angle in comparison to plain bladed weeding unit. The effect of diameter of weeding drum on performance index was found significant. But, the effect of blade angle and their interactions were found non-significant.
9. The minimum cost of operation 820.80 was observed in serrated bladed weeding unit of 100 mm diameter of weeding drum and 30°blade angle in comparison to plain bladed weeding unit. The effect of diameter of weeding drum on cost of operation was found significant. But, the effect of blade angle and their interactions were found non-significant.
10. The performance of the developed serrated bladed weeding unit was optimized for 100 mm diameter of weeding drum and blade angle 29.37°
11. The performance of the developed plain bladed weeding units was optimized for 100 mm diameter of weeding drum and blade angle 30.29°.

Conflict of Interest: None declared

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