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Response Surface Design Optimization for Blade Geometry of Non-Rotary Push-Pull Type Weeder

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ABSTRACT

Weeding is a time consuming as well as labor intensive operations creating low yield of crop. Manually operated push pull weeder mostly fabricated by local firms where dimensions, blade geometry and human safety and comfort were not considered precisely resulting lower weeding efficiency (WE). Present study was carried out for design optimization of blade geometry of push-pull weeder using response surface methodology (RSM). The selected independent parameters are angle of attack, approach angle and width of blade, where the responses are weeding efficiency, draft and plant damage. The design optimization was carried out for angle of attack 15º-50º, approach angle 30º-50º and width of blade 15-20 cm in five labels. Trials were carried out for a 0.25 ha plot of maize crop and 10 square plots of (1×1) m^2 were selected randomly for finding the average crop density, weed density, weeding efficiency and plant damage percentage for the same land. As per RSM analysis, five optimal solutions were found, where the optimum desirable conditions for maximum weeding efficiency (76.3%), minimum draft generated (34.9 kg) and minimum plant damage (0.102%) for the input variables viz. angle of attack as 15º, approach angle as 50º and effective width as 16.8 cm with the desirability of 0.872. In this optimal condition, farmers are comfortable with the weeder where minimum draft generated and can work for a longer duration with minimum stress along with better weeding efficiency.

Key words**:** Blade geometry, Optimization, Push-pull weeder, RSM

Weeding operation is the most vital agricultural activity. In India, this operation is mostly carried out traditionally with indigenous hand tools fabricated in local workshops. Manual weeding consumes extensive time and hard labor. In single manual hand weeding, the man-hour requirement is as high as 400 to 600 man-h/ha which amounts to Rs. 2200 per hectare [1-4] besides clean weeding but having slow in the process [5]. Weeds are accountable for substantial crop yield losses and financial losses in agricultural production by 10% per year globally [6]. Availability of the required number of laborers during peak seasons of the year because of this, some improved hand tools and implements have been developed including a manually operated push-pull weeder, with a field capacity higher than that of a hand tool. Blades incorporated in such a weeder vary in size and shape. There are claims and counterclaims of the superiority of one type of blade over the other, but no systematic evaluation has been carried out to assess the performance of this push-pull weeder using different blade arrangements. Hence, more study is required to determine the functional parameters through which optimum results can be achieved where optimum could be either a minimum or a maximum of a function of the design parameters [7]. An approach was incorporated to optimize the different blade geometry of the push-pull manual weeder by using response surface methodology (RSM). RSM is a statistical tool to develop an experimental model of an outcome for some input variables. When the underlying phenomenon is not well known or too complex to be modeled mathematically, in such cases, RSM is an appropriate technique [8].

In this study, a manually operated push-pull weeder was used for getting optimized conditions of blade geometry where major parameters which are responsible for efficient weeding operations are blade geometry and the way of attachment of the blade with the weeder frame. Now a day, the existing weeder is designed without any technical aspect which may lead to poor efficiency as well as stress towards the farmworkers, while designing implements researcher/manufacturer must consider human safety and drudgery while fixing the blade arrangement.

For getting an optimized design geometry of blade arrangement, the parameter which is responsible for weeding activities is chosen based on field survey and previous research data. However, depending on the experimental design technique, the total number of experiments required can be

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reduced [9]. An experimental design methodology in RSM is very efficient for obtaining the maximum amount of intricate information by saving significant experimental time, the material used for analyses and personnel costs [10]. The independent parameters of push-pull weeder are cutting angle or angle of attack, approach angle, effective blade width, etc. According to Prakash *et al.* [11] for some weeder, adjustable blades and rotary blades can influence the performance of the weeder. The most effective ways to control weed seedlings mechanically are by burying them at 1 cm depth and cutting them at the soil surface [12]. For efficient cutting of weed seedlings, the edge of cutting blades or sharpness should be sharped to some extent. The sharpness angle of the blade front was kept fixed at 15º [13-14] and the apex angle should be in the range of 60° to 90° [13]. Starkey and Simalenga [15], reported that the performance of a weeder depends on the condition of the weed population, crop type, soil characteristics, interface between soil and the soil acting elements of the weeder and blade design parameters. Blade attachment has a significant effect on the performance of the weeder. Increasing or decreasing the angle of attack varies the efficiency of the weeding operation. Payne and Tanner [16], reported the effects of angle of inclination for ease of scouring of soil over the tine and draft force required to move the tine through the soil. The draft force increases slowly for angles in the range of 10–50º; at larger angles, the draft force increases more rapidly [17]. Theoretically, an approach angle of 90º would affect a complete cut of all the roots [18]. However, when working near the soil surface with an attack angle of 15º and having an approach angle of 90º, blade penetration may be difficult, especially in hard soils [18]. Again, an attack angle of about 15° will produce good scouring with minimum draft force and an angle of less than 15º may not have sufficient lifting action and would leave the weeds in their original positions [14, [18-19].

The researcher attempted several approaches earlier to fix the blade geometry, but among all, it becomes a little difficult to suggest a suitable complete dimension of manual weeder to a farmer considering all aspects. To overcome this situation, the present study was carried out by using RSM in conjunction with Central Composite Rotatable Design (CCRD), which is less laborious and time-consuming [20] and requires fewer tests than a full factorial design [21] to establish the functional relationships between three operating variables of manually operated push-pull weeder namely cutting angle or angle of attack, approach angle, width of the blade with the response such as draft force, weeding efficiency and plant damage. After that, these relationships can then be used to determine the optimal conditions of functional parameters.

MATERIALS AND METHODS

Selection of an experimental plot

A 0.25 ha plot of maize (Zea mays) crop was selected for the field trials at Abhayapuri, Bongaigaon district of Assam. During physical observation, the test plots were randomly selected where on average, the row to row spacing was found 40-42 cm and plant to plant spacing was found 30-32 cm. The trial was carried out when the crop was around 28 days after sowing (DAS). At this stage, the density of both weeds and crops was calculated manually with randomly selected 10 square plots of (1×1) m^2 for finding the average crop density and weed density for the same land. The overall size of the experimental plot was selected as (4×10) m^2 [22]. The soil was sandy loam, and its bulk density was found 1.35-1.40 gm/cm^3 before weeding. Speed of operation is kept within the range of average normal walking speed which is around 0.9 to 1.10 km/h [23]. The depth of operation was calculated manually with the help of a measuring scale, and it was found in all the test plots approximately 4 cm with a standard deviation (SD) of 0.5 cm [14].

Fig 1 Existing wheel hoe

Existing push-pull weeder

A manually operated push-pull weeder is widely used in agriculture practices. Though, most of the wheel hoes are manufactured by the local firm where the dimension of blade and blade arrangement are not properly followed, for which the farmworkers are always facing difficulties in smooth functioning. The blade spacing and angle of attack were found different for different push-pull weeders along with different shapes and sizes. The average dimensions of five randomly selected existing wheel hoes (Figure1) taken from farmer's field in Bongaigaon District of Assam and from the Department of Agricultural Engineering, NERIST, Arunachal Pradesh such as angle of attack = 22-25º, approach angle = 40-45º, blade width =160-200 mm, wheel diameter = 400 mm, handle length = 1400-500 mm and handle height = 1100 mm.

Therefore, further modification is required for maximizing weeding efficiency along with minimizing draft requirement by changing the blade geometry and attachment through optimization considering weeding efficiency, draft and plant damage percentage as an output variable.

The general practice of determining this optimization is by varying one parameter while keeping the other at an unspecified constant level. The major disadvantage of this single variable optimization is that it does not include interactive effects among the variables; thus, it does not depict the net effects of various parameters on the reaction rate [20].

Draft

The draft is the force required to push or pull the tool for the weeding operation. The draft should be within the physiological limit of the operator for manually operated soil working tools. The draft can be determined by using the following Eqn. [24]

$$D_w = W \times d_c \times R_s$$

Where, D_w = Draft force generated N, d_c = Depth of operation (cm), W = effective width of cut (cm) and R_s = specific soil resistance (N/cm^2).

Weeding efficiency

Weeding efficiency (WE) in each randomly selected test plot of 1m × 1m size is calculated by using the following standard eqn. [24] by manual counting of weeds before operation and after operation for the randomly selected square plot of 0.25 m^2 as-

$$WE(\%) = \frac{W_b - W_a}{W_b} \times 100$$

Where, W_b is the number of weeds before weeding operation in the same test plot
W_a is the number of weeds after the weeding operation in the same test plot

Plant damage

Plant damage (PD) is the degree of damage or injury to plants during a weeding operation. It was detected in terms of cutting plant leaves as well as buried plants by soil mass due to the impact of cutting blades. The method was carried out by counting the number of plants in randomly selected (10 m×1 m) row lengths before and after weeding and thereafter percentage of PD was calculated by using the following relation [25].

$$PD(\%) = \frac{Q_a}{Q_b} \times 100$$

Where, Q_b= Total number of plants in 10 m length before weeding
Q_a = Total number of plants damaged in 10 m length after weeding

Experimental design

In this study, RSM was applied to find the effect of independent variables such as angle of attack (degree), approach angle (degree), and the effective width of the blade (cm) on responses such as weeding efficiency (%), draft generated (Kg), plant damage (%). The values of angle of attack varies from 15º to 50º, approach angle varies from 30º to 50º and width of blade varies from 15 cm to 20 cm. Data analysis and model fitting were carried out using design expert software (Version 13.0.7.0, Stat-Ease Inc., Minneapolis, MN, Trial version). The coded and un-coded values of experimental designs were shown in (Table 1). CCRD was used along with the quadratic model [8] and it requires five levels for each independent variable [21]. Each independent variable namely angle of attack (A), approach angle (B) and effective blade width (C) contains five levels of coded values, viz., -α, -1, 0, +1, +α, were selected [26]. A total of 20 different combinations were obtained in a randomized order as par CCRD configuration for independent factors [27].

In the RSM analysis, independent variables A, B and C are converted into coded variables using the following Eqn (1) [28]-

$$\varepsilon_i = \frac{x_i - [\max(x_i) + \min(x_i)]/2}{[\max(x_i) - \min(x_i)]/2} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where ε_i is the coded value in five levels for the independent variables of A, B and C; x is the natural variable of independent variables of A, B and C. Also, maximum (x) and minimum (x) are the two end values of the natural variable. The relationship between coded and actual values of a variable [29] is shown in (Table 1-2), where the coordinate for axial points (Eqn. (2) & (6)), central points (Eqn. (4)) and factorial points (Eqn. (3) & (5)) were determined.

Table 1 Relationship between coded and actual values of variable

Code	Actual value of variable	
-α	minimum (x)	(2)
-1	[maximum (x) + minimum (x)] / 2 - [maximum (x) – minimum (x)] / 2α	(3)
0	[maximum (x) + minimum (x)] / 2	(4)
+1	[maximum (x) + minimum (x)] / 2 + [maximum (x) – minimum (x)] / 2α	(5)
+α	maximum (x)	(6)

Where, $\alpha=2^{k/4}$; k = number of independent variables (here, α=1.682).

Fig 2 Fabricated blade assembly

Fig 3 Operation with modified weeder

As per combinations obtained from CCRD, fabrication of the weeder blade was done accordingly in the workshop of Abhayapuri, Assam as shown in (Fig 2) and all the combinations were taken for weeding operation in the test field for getting the optimum combination as shown in (Fig 3). While designing these experiments, 2nd order polynomial Eqn. was developed to define weeding efficiency (Y_1), draft (Y_2) and plant damage (Y_3) as a function of independent variables. It is given in Eqn. (7).

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_i \sum_j \beta_{ij} X_i X_j + \varepsilon \ \ldots.. (7)$$

Where Y is the response; β_o is the intercept; β_i β_{ii} and β_{ij} are the linear, quadratic, and interactive coefficients respectively and these coefficients were further determined by using analysis of variance (ANOVA) in RSM**;** X_i, and X_j are the coded variables and ε is the error.

Table 2 CCRD employed for independent variables and their corresponding levels in developing response functions

Independent variables	Code	Coded levels				
		-1.682(-α)	-1	0	+1	+1.682(+α)
Angle of attack, (º)	X_1	3.07	15	32.5	50	61.93
Approach angle, (º)	X_2	23.18	30	40	50	56.82
Width of blade, (cm)	X_3	13.30	15	17.5	20	21.70

Statistical analysis

The experimental data was focused on analysis through multiple regressions to fit the 2nd order polynomial equation for independent variables. ANOVA was implemented to find the significant difference between the selected variables by figuring the F-value at probability (p) 0.01, 0.05 and 0.1. To envisage the effect of independent variables on response variables, contour plots and response surface plots were created by using response surface methodology (RSM).

RESULTS AND DISCUSSION

Fitting the model

The investigation was carried out for weeding efficiency, draft, and plant damage with different independent variables viz. angle of attack, approach angle and effective width of blade assembly to obtain responses. Response surface analysis was applied to 20 experimental runs where the predicted values of responses were in remarkable agreement with the experimental one obtained from the response surface methodology (RSM) design as shown in (Table 3). The actual and predicted weeding efficiency, draft and plant damage are plotted. The coefficients of the 2nd order polynomial equation were derived from the experimental data to obtain the significance of the model suggested by the response surface methodology (RSM) design. Regression analysis and ANOVA were carried out for fitting the model equation to inspect the statistical significance of model terms. Values in brackets are the uncoded values for independent variables.

Table 3 Central composite rotatable design (CCRD) design with coded and uncoded independent variables and experimental values

Independent variables				Dependent variables (Response, Y)					
Run No	A: Angle of attack	B: Approach angle	C: Width of blade	Weeding efficiency		Draft		Plant damage	
	X_1 (°)	X_2 (°)	X_3 (cm)	Percent		Kg		Percent	
				Actual	Predicted	Actual	Predicted	Actual	Predicted
1	-1 [15]	+1 [50]	-1 [15]	78	77.35	35	34.76	0.1	0.0962
2	+1.68 [61.93]	0 [40]	0 [17.5]	75	76.12	42	43.61	0.14	0.1626
3	+1 [50]	-1 [30]	-1 [15]	70	69.48	39	38.90	0.1	0.0976
4	0 [32.5]	0 [40]	0 [17.5]	79	79.35	37	34.76	0.12	0.1162
5	-1 [15]	-1 [30]	-1 [15]	68	70.10	35	34.29	0.11	0.0900
6	0 [32.5]	0 [40]	0 [17.5]	79	78.50	37	34.76	0.12	0.1162
7	+1 [50]	+1 [50]	+1 [20]	78	77.67	41	45.85	0.18	0.1612
8	0 [32.5]	0 [40]	0 [17.5]	79	78.32	37	34.76	0.12	0.1162
9	0 [32.5]	0 [40]	0 [17.5]	79	80.70	37	34.76	0.12	0.1162
10	+1 [50]	+1 [50]	-1 [15]	77	79.64	40	42.29	0.17	0.1563
11	0 [32.5]	0 [40]	+1.68 [21.7]	81	79.34	41	40.90	0.16	0.1267
12	0 [32.5]	+1.68 [56.82]	0 [17.5]	82	81.24	40	41.01	0.12	0.1193
13	+1 [50]	-1 [30]	+1 [20]	72	73.24	39.5	41.88	0.13	0.1601
14	-1.68 [3.07]	0 [40]	0 [17.5]	55	56.37	34	32.20	0.12	0.0699
15	0 [32.5]	0 [40]	-1.68 [13.3]	69	68.20	34.5	36.60	0.12	0.1058
16	0 [32.5]	0 [40]	0 [17.5]	79	80.15	37	34.76	0.12	0.1162
17	0 [32.5]	-1.68 [23.18]	0 [17.5]	72	70.19	36.5	37.29	0.11	0.1132
18	-1 [15]	+1 [50]	+1 [20]	83	85.14	36	36.88	0.13	0.0586
19	-1 [15]	-1 [30]	+1 [20]	69	71.29	36	35.85	0.14	0.1100
20	0 [32.5]	0 [40]	0 [17.5]	79	79.90	37	34.76	0.11	0.1162

From (Table 3), it was found that the experimental value of responses is in notable agreement with the predicted values found in the CCRD of RSM design. Further calculation of those response values for finding the coefficients of 2nd order polynomial equation were carried out to obtain the output variables such as wedding efficiency, draft generated by the weeding blade and plant damage percentage during weeding operation. The following regression equations were generated from the design experiment for wedding efficiency (Eqn. (8)), draft (Eqn. (9)) and plant damage (Eqn. (10)).

$$\text{Weeding Efficiency } (Y_1) = +73.17-0.5193X_1+3.16X_2+3.51X_3-1.69\,X_1X_2-3.69\,X_1X_3+0.5625\,X_2X_3-5.02X_1^2-0.4263X_2^2+0.8140X_3^2 \quad (8)$$

$$\text{Draft } (Y_2) = +34.76+3.39X_1+1.11X_2+1.28X_3+0.7325X_1X_2+0.3575X_1X_3+0.1425X_2X_3+1.11X_1^2+1.55X_2^2+1.42X_3 \quad (9)$$

$$\text{Plant Damage } (Y_3) = +0.1162+0.0276X_1+0.0018X_2+0.0062X_3+0.0131X_1X_2+0.0106X_1X_3-0.0144X_2X_3 \quad (10)$$

ANOVA was performed to check the significant difference between these variables by computing the F-value at $p<0.05$ and it was found that the quadratic polynomial model is satisfactory to represent the experimental data of weeding efficiency and draft whereas the two-factor integral model for plant damage was suggested for experimental analysis. To visualize the effect of independent variables on response variables, contour plots and response surface plots were created by using CCRD in RSM. Model summary statistics also suggest that the quadratic model for weeding efficiency has a coefficient of determination R^2 value is 0.8328, R^2 for a draft is 0.9693 and for Plant damage, the two-factor integral model (2FI) has R^2 value of 0.8247. A higher the R^2 indicated a good agreement of the outcome to the suggested model in estimating the approach angle, angle of attack and effective width of the blade. In statistical analysis, R^2 is a computation of the amount of variation around the mean described by the model. However, a large value of R^2 can be misleading if the model contains unnecessary terms [30-31]. R^2 always increases by adding factors to the model whether the additional factor is significant or not. Generally, the adjusted R^2 value does not increase as factors are added to the model. Larger variations between R^2 and R^2_{adj} indicate that non-significant terms are involved in the model [30-31]. Further, it was checked through statistical analysis for the adequacy of the suggested model, which revealed that there was no lack of fit in the proposed model showing R^2 value closer to unity indicating a better empirical model fit to actual data. A lesser value of R^2 indicates that dependent variables were less relevant to explaining the variation of behavior [32]. It was found from the lack of fit test; that the selected models have an insignificant lack of fit value ($p<0.05$).

From ANOVA, for weeding efficiency, the model is significant having an F value of 5.56 ($p<0.05$) where lack of fit is insignificant, also approach angle (B), width of the blade (C), the interaction of angle of attack and width of the blade (AC) and quadratic term of the angle of attack (A^2) is significant at $p<0.05$ with SD as 4.08, C.V% as 5.83, R^2 value as 0.8328 and adequate precision is 8.3411 (>4 which is desirable). For draft analysis, the model is significant having an F- value of 35.05 ($p<0.01$), where lack of fit is insignificant. In this case, the linear term of the angle of attack (A) is highly significant at p<0.01, and the approach angle and width of the blade are significant at P<0.05 having a high value of F (Table 3), where the interaction terms AB, AC and BC are not significant. But the quadratic term of the angle of attack (A^2), approach angle (B^2) and width of the blade (C^2) is significant at P<0.05.

ANOVA analysis

Regression coefficient

Table 4 Regression coefficient values of different responses by using RSM

Source	Weeding efficiency	Draft	Plant damage
Intercept	73.17*	34.76*	0.1162**
X_1 (A)	-0.519	3.39**	0.0276**
X_2 (B)	3.16*	1.11*	0.0018
X_3 (C)	3.51**	1.28*	0.0062
X_1X_2 (AB)	-1.69	0.7325	0.0131**
X_1X_3 (AC)	-3.69*	0.3575	0.0106***
X_2X_3 (BC)	0.5625	0.1425	-0.0144*
X_1^2 (A^2)	-5.02**	1.11*	
X_2^2 (B^2)	-0.4263	1.55*	
X_3^2 (C^2)	0.8140	1.42*	
R^2	0.8328	0.9693	0.8247
Adjusted R^2	0.6823	0.9416	0.7439
Predicted R^2	0.3080	0.8072	0.2146
Adeq. PRESS	8.3411	20.8642	11.2682
Std. dev.	4.08	0.9252	0.0156
C.V.	5.83	2.46	13.42
Lack of Fit	0.1345ns	0.0946 ns	0.0936 ns

*Significant (p<0.05)
**significant (p<0.01)
*** significant (p<0.1), ns-not significant

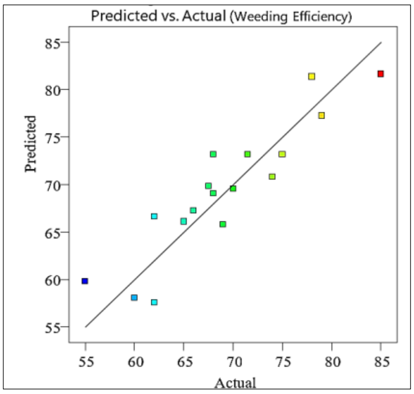

Fig 4 Predicted value vs actual value of weeding efficiency

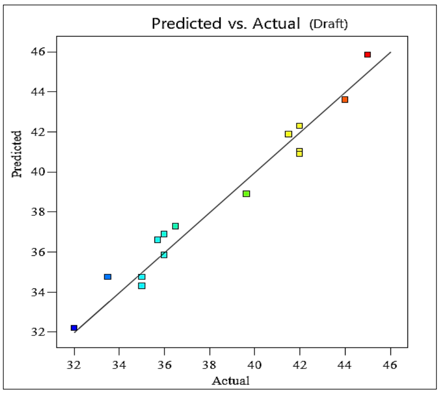

Fig 5 Predicted value vs actual value of draft

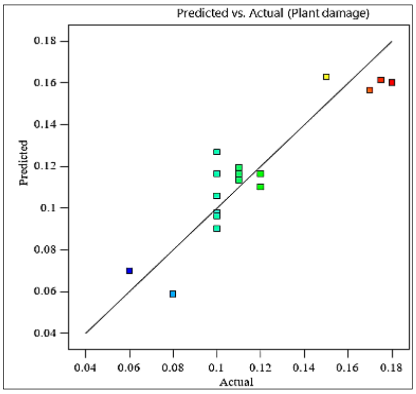

Fig 6 Predicted value vs actual value of plant damage

After generating the final equation (Eqn. (8), (9) and (10)), the actual and experimental values were compared with the predicted value which comes from the regression model. From Figure 4-6, the actual values were well distributed relatively near to the predicted line showing a decent correlation between the actual and predicted values. It shows good fitting the regression equation and the central composite design model with an experimental design can be effectively applied for optimization [33-34].

Effect of angle of attack and width of the blade on weeding efficiency, draft and plant damage

From the analysis, it was observed that the Weeding efficiency of the wheel hoe has a strong relationship with the angle of attack towards the soil, approach angle and effective width of blade. It was observed that weeding efficiency at fixed blade width of 17.5 cm (Fig 7), is gradually increasing with increasing the angle of attack up to 15-20º along with decreasing the approach angle from higher to lower and thereafter decreases as draft increases for further increases of angle attack. Similar results were found for 15º [35], also an angle less than 15º may not have sufficient lifting action and would leave the weeds in their original position [17], which justifies the present study. From Figure 8, it was observed that draft is minimum at a lower angle of attack and approach angle at constant blade width of 17.5 cm and thereafter there is abruptly increasing the draft [17], reducing the angle of attack will reduce the normal force and frictional component of horizontal force acting on tyne [16]. At the fixed width of the blade, increasing the approach angle and decreasing the angle of attack resulted in a less percentage of plant damage (Fig 9) because good soil scouring and high weeding efficiency [17] were observed as a smaller number of push-pull action is required to complete the operation. The greater number of repeated works near the crop root area may increase the plant damage percentage if the plants are not firmly anchored.

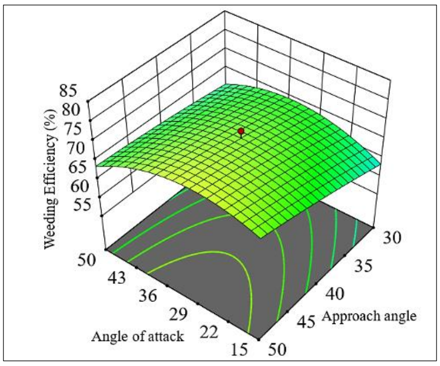

Fig 7 3D ghraphical interpretation of wedding efficency as a function of angle of attack and approach angle at fixed width of 17.5cm

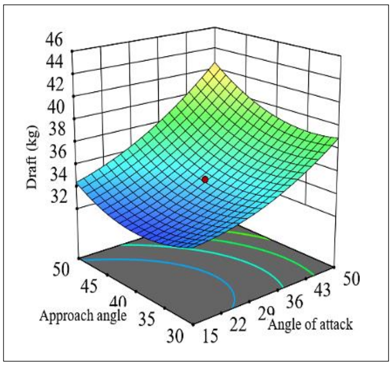

Fig 8 3D ghraphical interpretation of draft as a function of angle of attack and approach angle at fixed width of 17.5cm

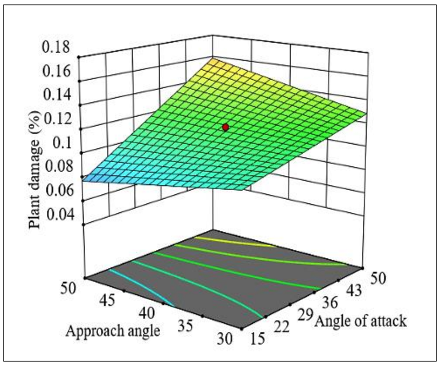

Fig 9 3D ghraphical interpretation of wedding efficency as a function of angle of attack and approach angle at fixed width of 17.5cm

Effect of angle of attack and width of the blade on weeding efficiency, draft, and plant damage

Changing the effective blade width along with changing the angle of attack has shown significant variation in weeding efficiency, draft, and plant damage. As increases, the blade width, increases weeding efficiency as a large number of weeds may be uprooted but it may create more draft for the higher angle of attack which is not feasible for the farmer to continue the operation for a longer duration resulting in less effective field capacity. In this study (Fig 10), weeding efficiency was found optimum at around 17-20 cm of blade width at a lower angle of attack. Similar results were also found by Simour and Verma [36]. Draft generated during weeding operation is maximum at increasing width of the blade and higher angle of attack at a fixed approach angle of 40º (Fig 11) whereas minimum draft was observed at a lower angle of attack around 15-20º and plant damage percentage is maximum at higher width and higher angle of attack (Fig 12).

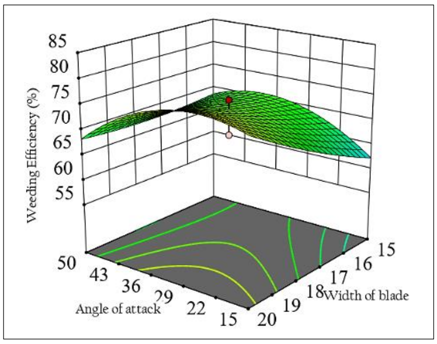

Fig 10 3D Graphical interpretation of wedding efficiency as a function of angle of attack and blade width at a fixed approach angle of 40º

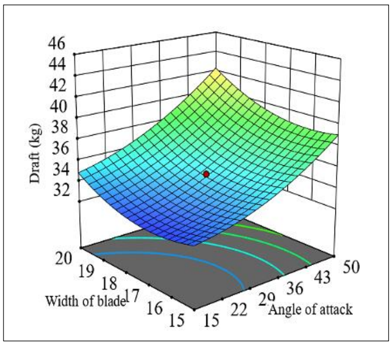

Fig 11 3D Graphical interpretation of draft as a function of approach angle and a blade width of the blade at a fixed approach angle of 40º

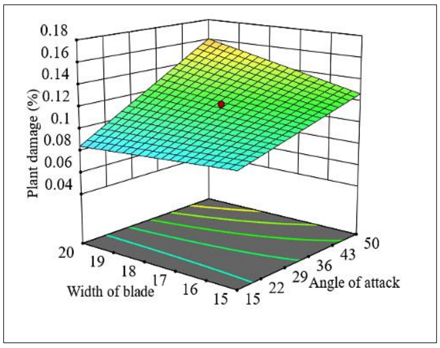

Fig 12 3D graphic surface optimization of plant damage as a function of angle of attack and width of the blade at a fixed approach angle of 40º

Effect of approach angle and width of the blade on weeding efficiency, draft, and plant damage

From (Fig 13-15), it was observed that weeding efficiency increased at a higher approach angle, similar results were found by Sims [17] 2000 and an effective blade width of 17-19 cm (approx.) where minimum draft is generated. At this condition, plant damage percentage was also found minimum at a fixed angle of attack of 32.5°.

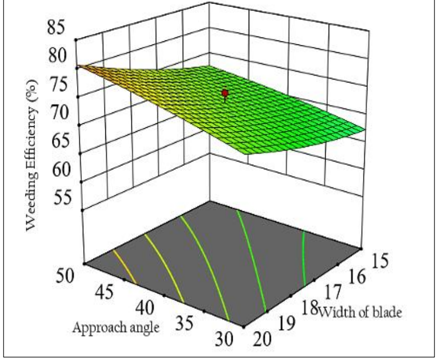

Fig 13 3D graphical interpretation of wedding efficiency as a function of approach angle and blade width at a fixed angle of attack-32.5º

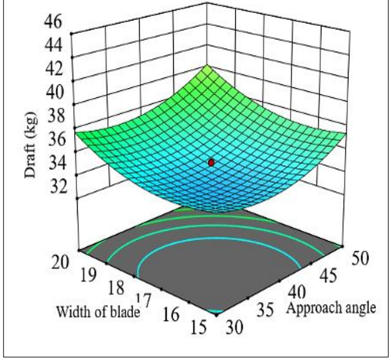

Fig 14 3D graphical interpretation of draft as a function of approach angle and blade width at a fixed angle of attack-32.5º

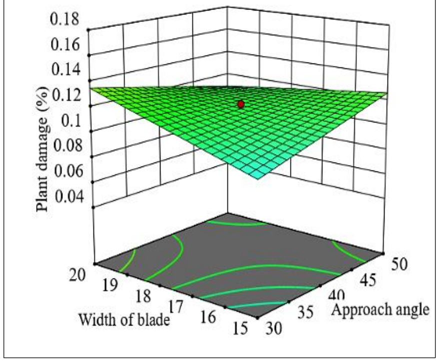

Fig 15 3D graphical interpretation of plant damage as a function of approach angle and blade width at a fixed angle of attack-32.5º

From the analysis of RSM, five optimal conditions of independent variables along with the best suitable responses with higher desirability (Table 5) were observed. Among all five solutions, the best optimal condition was found as the angle of attack as 15°, approach angle as 50° and effective blade width as 16.8 cm with a desirability function of 0.872 (Table 5) and corresponding response as WE is 78.1%, D as 34.9 kg and PD percentage as 0.102%. Further increases the angle of attack, draft will also increase [17-18] and however for good uprooting of weeds, the approach angle should be higher [18] which was also a similar result for the current study i.e., 50° but further increasing up to 90° may create difficulties in penetration [19]. A similar study was carried out by Singh [14] for different types of weeder blades where wheel hoe with Tyne blade showed as weeding efficiency of 75.71% having blade width of 18 cm and draft generated was 37.48kg.

Table 5 Optimum conditions of responses

S. No.	Angle of attack (X_1)	Approach angle (X_2)	Blade width (X_3)	WE (%)	D Kg	Plant disease (%)	Desirability
1	15.0	50.0	16.8	76.3	34.9	0.102	0.872
2	15.0	50.0	16.7	76.2	34.9	0.101	0.872
3	15.2	50.0	16.8	76.5	34.9	0.102	0.871
4	15.0	49.8	17.0	76.5	34.9	0.102	0.870
5	16.0	50.0	17.8	78.1	35.3	0.107	0.858

It was found that the weeding efficiency is higher in solution number 5 (Table 5) as WE as 78.1%, D as 35.3 kg for angle of attack 16° and approach angle of 50° and width of blade as 17.8 cm (Fig 16, Table 5), where the draft is slightly higher value i.e. 35.3 kg but for manual hand tools having higher draft may create stress and fatigue while operation, also required more power to operate [14] and from desirability function value, it is slightly lower than the solution where the angle of attack 15°, approach angle 50° and blade width 16.8 cm. With these combinations, weeding efficiency can be improved if weeding operations are conducted in criss-cross pattern where sufficient plant to plant distance should be required.

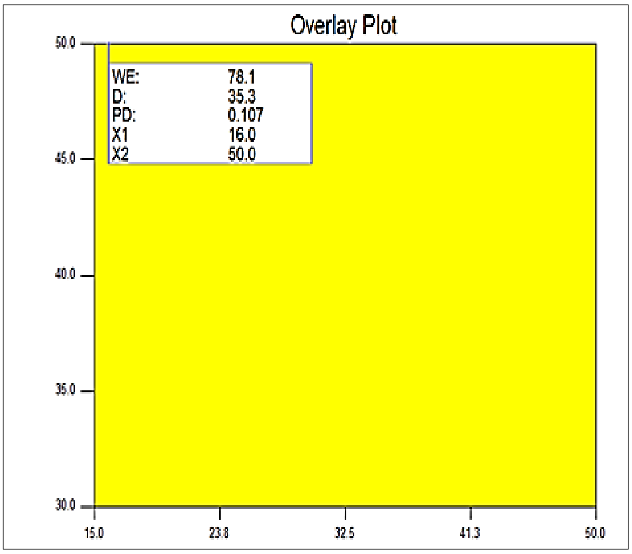

Fig 16 Overlay plot for weeding efficiency

CONCLUSION

The present study revealed that the quadratic model was sufficient to predict and describe the responses of weeding efficiency and draft, but two factor integral model was sufficient to predict the response of plant damage with the change of angle of attack, approach angle and effective width of the blade. The lack of fit is insignificant for all three selected models and shows a good fit between the actual value and the predicted value. The optimal solution was obtained from the RSM analysis using the desirability function to obtain desirable solutions. The optimum desirable conditions for maximum weeding efficiency, minimum draft generated while weeding operation and minimum plant damage in percentage were found for the angle of attack as 15º, approach angle as 50º and effective width of the blade as 16.8 cm with the desirability of 0.872. In this condition, farmers are comfortable with manually operated wheel hoes having minimum draft generated and can work for a longer duration without stress.

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Conflict of interest

Declared by all authors that they have no conflict of interest of the content presented in this paper.

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