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Optimization of the performance parameters of hoe type ridger under laboratory condition of vertisol (Black soil) by using response surface technique

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Abstract

The goal of this study is to evaluate the performance parameters and their effects on horizontal force F_x (draft force), vertical force F_y (vertical reaction), and height of ridge for hoe type ridger during the operation in vertisol soil under controlled soil bin condition and optimize the best combination of width of cut, operational depth, and forward speed for hoe type ridger. All the fabrication work and experiments were completed in workshop and indoor soil bin laboratory of Department of Farm Machinery and Power Engineering, College of Agricultural Engineering, JNKVV, Jabalpur. After completing all experiments on the basis of Randomised Block Design (RBD) pattern and optimise the experimental data by using Box-Behnken Design (BBD) of Response Surface Method (RSM). The optimised solution from all experiments, we found a combination of all independent and dependent variables. The value of horizontal force F_x 1353.57 N, vertical force F_y 2731.21 N, and height of ridge 67.28 mm at 2.172 km/h forward speed, 40 cm width of cut, and 9.72 cm operational depth for the designed hoe type ridger.

Keywords: Hoe type ridger, soil bin, vertisol, draft force, box-Behnken design

1. Introduction

Tillage tools are mechanical devices and the mechanics of tillage tools are fundamental to the field of agriculture as they enable us to apply forces to the soil in a way that achieves specific agricultural goals (Ani *et al*. 2018) [3]. By understanding the mechanics, we can design more effective tools and develop better techniques for soil preparation and cultivation (Sawant *et al*. 2016, Upadhyay and Raheman. 2018) [19, 21]. This knowledge is crucial for improving agricultural practices and increasing productivity while minimizing environmental impact (Nandede *et al*. 2014) [15].

A ridger is a farming tool employed to simultaneously cuts and turns the soil in two opposing directions, creating ridges (Singh *et al*. 2016 and Altuntas *et al*. 2006) [20, 2]. Typically, a ridger features a wedge-shaped share or V-shaped blade and consists of essential components such as a guide wall, ridger column, and ploughshare (Singh *et al*. 2016 and Giron *et al*. 2005) [20, 5]. The guide wall can be divided into a chest and a wing (Nandede *et al*. 2014 and Kumar *et al*. 2018) [15, 12]. The ridger column and guide wall are assembled in combination to facilitate replacement (Kumar *et al*. 2017, and Ani *et al*. 2018) [9, 3]. The front part of the ploughshare is pointed, and the cutting edge is not perpendicular to the direction of the cutting motion obliquely, leading to oblique cutting, reducing the impact, and stabilizing the process of cutting soil by the ridger (Nandede *et al*. 2014 Nandini *et al*. 2023, and Singh *et al*. 2016) [15, 16, 20]. To facilitate the control of the soil flow direction, the guide wall surface was designed with a gentle crest and low distortion, which is beneficial to the upward sliding of soil along the surface; the guide wall surface has a longer wing and larger distortion, which is convenient for lateral tillage and pushes the soil to both sides of the ridger (Darmora *et al*. 1995) [4]. Therefore, many forces act on the ridger while it operates in soil under various operational depth, width of cut, forward speed, and soil conditions

(Kumar *et al*. 2017, and Sawant *et al*. 2016) [9, 19].
The performance of hoe type ridger is usually evaluated using draft, vertical force, and lateral force exerted on the ridger by the soil (Sawant *et al*. 2016, Darmora *et al*. 1995, and Kepner *et al*. 1978) [19, 4, 8]. Associated with these are the geometry of the furrow created by the ridger (Ani *et al*. 2018) [3]. Soil failure geometry is expressed in terms of rupture distance, failure angle, depth of cut, size of the side failure crescent (Roul *et al*. 2020) [17], cross sectional area of cut, and volume of soil failed (Altuntas *et al*. 2006) [2]. Using these parameters, the efficiency of the operation can be expressed in terms of the specific draft, or the energy expended per unit volume of soil disturbed **(**Godwin *et al*. 1993) [6]. The precise amount of force required to pull agricultural tools or implements can vary significantly depending on various factors (Nandede *et al*. 2014) [15]. These factors encompass the type and condition of the soil (Roul *et al*. 2020) [17], the attachments used, friction properties of the surfaces that interact with the soil (Gupta and Surendranath. 1989) [7], the characteristics of the plough's bottom, ploughing depth, speed, width of the furrow slice, sharpness and shape of the share, and the tool's and attachments' settings (Singh *et al*. 2016, Kumar *et al*. 2023a) [20, 10].
Performance evaluations of various types of ridgers and furrow openers in laboratory condition as well as in actual field condition have been studied by several researchers (Singh *et al*. 2016 and Manuwa. 2009) [20, 13]. The results showed that the characteristics of the ridgers and furrow openers have affected soil parameters, and draft forces (Giron *et al*. 2005, Altuntas *et al*. 2006 and Darmora *et al*. 1995) [5, 2, 4]. Causing more energy requirement to complete an operation of tillage or making ridges and furrows at various operational depth (Roul *et al*. 2020, and Manuwa. 2009) [17, 13], and forward speed (Godwin *et al*. 1993, and Giron *et al*. 2005) [6, 5]. So, having precise information about the draft and energy requirements of tillage implements is critical for designing a tool effectively, ensuring a suitable matching with their power sources, and selecting the most suitable operational conditions (Singh *et al*. 2016 and Kepner *et al*. 1978) [20, 8]. It is important to know how much energy or forces will require to drag a tillage tool and also should be know which kind of factors will affect the performance of designed tillage tool for various operations (Gupta and Surendranath. 1989, Sawant *et al*. 2016 and Nandede *et al*. 2014) [7, 19, 15]. The utilization of soil bin investigation of tillage tools is essential for the advancing and enhancing in the performance of tillage implements (Nandede *et al*. 2014, Ani *et al*. 2018, and Singh *et al*. 2016) [15, 3, 20]. Soil bin systems provide a platform for conducting tests under precisely controlled or specific soil conditions (Namdeo *et al*. 2022, and Kumar *et al*. 2017) [14, 17], where soil is brought to the test bed have been used to acquire a significant amount of data (Sawant *et al*. 2016) [19]. The data to be optimized by using various techniques for statistical analysis of variance of different independent variables to optimize the solution for dependent variables of soil bin tests (Kumar *et al*. 2017, and Rubinstein *et al*. 1994) [9, 18].

2. Materials and Methods
The detailed data or information about material and methods adopted for the design, improvement, testing, and performance evaluation of hoe type ridger (Nandede *et al*. 2014, and Kumar *et al*. 2023b) [15, 10]. The hoe type ridger was developed by the mechanical, agronomical, and economical parameters according to Indian circumstances (Giron *et al*. 2005, and Kepner *et al*. 1978) [5, 8]. Solid Works 2016 were utilized to design and analysis for the components of the machine though the statistical analysis software named as Design Expert 14 was utilized for the performance optimization of the soil engaging tools of the machine (Rubinstein *et al*. 1994) [18].

2.1 Design and development of hoe type ridger
After studied many literatures and reviewed them and found, the ridger is used to perform many agricultural works in field likewise; vegetable planter, sugarcane planter, making furrows for irrigation (Nandede *et al*. 2014, and Roul *et al*. 2020) [15, 17], and also used for making or shaping a raised and broad soil bed for sowing the crops (Singh *et al*. 2016 and Kumar *et al*. 2017) [20, 9]. The hoe type ridger was fabricated as per the Indian standards in the workshop of the Department of Farm Machinery and Power Engineering, College of Agricultural Engineering, JNKVV, Jabalpur. The designed and developed ridger having bottom length 270 mm, height of frog 110 mm, length, and width of the wings 280 and 200 mm, height, width, and thickness of shank 675, 65, and 12 mm, and pointed type shear was used for the hoe type ridger which illustrated in Plate 1 (Nandede *et al*. 2014) [15]. There was a width adjustment setup given in the ridgers for adjust the opening of wings from 200 mm to 400 mm (Gupta and Surendranath. 1989, and Kumar *et al*. 2017) [7, 9].

Plate 1: Developed hoe type ridger

2.2 Soil bin test setup for the experiment
Soil bin facility is equipment for scale model tests and experiments for soil-machine interaction (Sawant *et al*. 2016) [19]. The stationary soil bin had a length of 20.0 m, a width of 2.37 m, and a height of 1.02 m depicted in Plate 2a and a control room unit to control the movement of trolley picture in Plate 2b. The soil processing trolley and test trolley were to be run on the rail during test (Nandede *et al*. 2014) [15]. The soil processing trolley was connected with a rotavator for soil bed preparation (Kumar *et al*. 2017) [9], a leveller for levelling out the soil bed, a roller compactor for keeping up with soil compactness, and a water tank with nozzles for keeping up with the moisture content of the soil (Sawant *et al*. 2016) [19]. Test trolley for testing of the tools was related with provision for testing of both active and passive type tillage tools (Ani *et al*. 2018, and Upadhyay and Raheman. 2018) [3, 21]. The test trolley was well equipped with the various kinds of the transducer as; cone penetrometer with force (type U9C/5 kN) and displacement transducer (type WA/200 mm) for estimating the soil compaction (Nandede *et al*. 2014) [15]. Extended octagonal ring transducer (EORT) having a force limit of 5 kN which used to measure the force acting on tillage tools in horizontal direction (Fx), vertical direction (Fy), and moment (My) illustrated in Plate 2c (Godwin *et al*. 1993 and Upadhyay and Raheman. 2018) [6, 21]. Torque transducer for measurement of the torque of rotary-type tillage tools. A 16 channel DAS (Data Acquisition system shown in Plate 2d) hardware for data acquisition and analogue to digital conversion for further processing **(**Godwin *et al*. 1993) [6]. It was connected to the computer to display and record real-time data directly in the Catman Easy software (Namdeo *et al*. 2022) [14].

Plate 2a: Soil bin test setup

Plate 2b: Soil bin control room

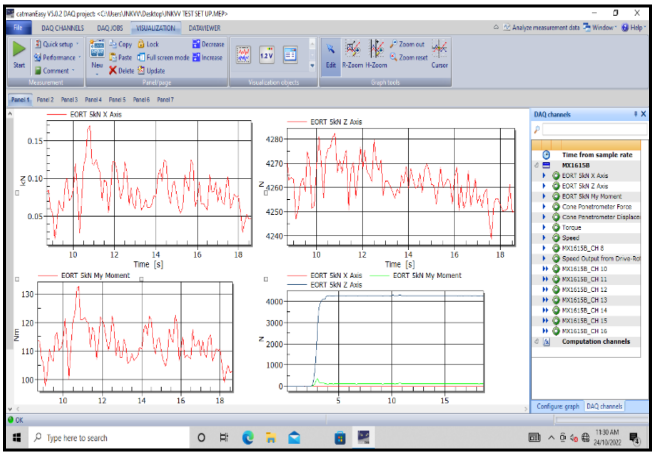

Plate 2c: Real time force analysis by Catman Easy

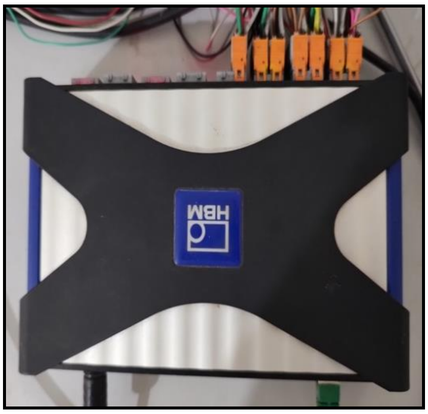

Plate 2d: Data acquisition system

2.3 Experimental design of hoe type ridger
The performance parameter of hoe type ridger was taken as responses were a draft force in the x-direction (N), force in the y-direction (N), and ridge height (mm) (Altuntas *et al*. 2006 and Singh *et al*. 2016) [2, 20]. These performance parameters were measured at selected independent variables three levels of forward speeds of operation (i.e.1.5, 2, 2.5 km/h), three level width of cut (20, 30 and 40 cm) and three levels of depths (8, 12, and 16 cm) at 600±30 kPa cone index and 14-15% of moisture content under the controlled soil bin condition (Sawant *et al*. 2016 and Kumar *et al*. 2017) [19, 9]. The soil bin was filled with black cotton soil (Vertisol) constitutes 32% sand, 22% silt, and 53.6% clay (Manuwa. 2009) [13]. This study hypothesized that the width of cut (cm), the forward speed of operation (km/h), and operational depth (cm) were the independent variables responsible for the observed effects on the dependent variables or functional response (Upadhyay and Raheman. 2018) [21]. It is necessary to consider the interactions between different operational factors since their effects may not be completely distinct from one another (Ani *et al*. 2018) [3].

2.4 Optimization technique for optimize the experimental responses
A type of statistical analysis software known as Design Expert 14 is use to generate the response surfaces (Rubinstein *et al*. 1994 and Namdeo *et al*. 2022) [18, 14]. In order to evaluate the analysis of variance, a model is

constructed, and analysis is complete (Almaliki. 2018) [1]. Box-Behnken Design (BBD) procedures are often utilized for the study of factors in three levels of three-factor studies (Namdeo *et al*. 2022) [14]. These techniques are one of the many types of models that are used in the design of experimental investigations. It was necessary to determine the proper approximation for the genuine functional connection between operational components and the surface of the response (Rubinstein *et al*. 1994, and Almaliki. 2018) [18, 1].

3. Results and Discussion

While operating hoe type ridger the cutting, lifting, pulverization, and partial inversion of the soil take place. These actions of cutting, lifting, and inversion resulted in the soil force which acts on the hoe type ridger. These forces, along with any parasitic forces, are represented by a total force, which can be considered as the product of three components: longitudinal force, lateral force, and vertical force. The failure and displacement pattern of the soil by hoe type ridger in controlled soil bin condition, shown in Plates 3a, 3b, 3c, and 3d, which was created by running a hoe type ridger beneath a vertisol-filled soil bin. The results were analysed and evaluated as per randomized block design using the same experimental design given in Table 1.

Table 1: Optimized result of all responses from Box-Behnken design

Run	Forward speed (km/h)	Width of cut (cm)	Operational depth (cm)	Force in horizontal direction (N)	Force in vertical direction (N)	Ridge height (mm)
1	2	30	12	1300.24	3239.03	74
2	2	30	12	1304.78	3245.5	74
3	1.5	20	12	1141.34	4134.2	78
4	2.5	20	12	1306.37	4787.14	55
5	1.5	40	12	1334.55	3168.05	86
6	2	20	16	1396.14	5553.25	81
7	1.5	30	16	1411.21	4703.7	96
8	2	40	8	1257.24	2369.8	65
9	2	40	16	1632	4484.02	89
10	2	30	12	1306	3240.95	74
11	2.5	30	16	1619.5	5296.2	73
12	2	30	12	1302.2	3235.08	75
13	2	20	8	1080.77	3353.5	53
14	2.5	30	8	1244.12	3142.1	48
15	1.5	30	8	1086.84	2539.8	68
16	2.5	40	12	1529.14	3700.98	66
17	2	30	12	1308.45	3241.25	75


Plate 3a: Soil failure pattern **Plate 3b:** Ridger in operation


Plate 3c: View of ridge **Plate 3d:** Ridge height marking

3.1 Force acting on ridger in the horizontal direction X (F_x)

During the indoor laboratory soil bin test, among the total 17 experimental runs to be conducted for experiment. The maximum value of F_x was found 1632 N at the 16 cm operational depth, 40 cm width of cut, and 2 km/h forward speed of test trolly. Whereas, the minimum value of the F_x was found 1080.77 N for hoe type at 8 cm operational depth, 20 cm width of cut, and 2 km/h forward speed of the test trolley.

3.1.1 Effect of width of cut and operational depth on force acting in x direction

The responses of the force acting on horizontal direction F_x on the interaction of two variables width of cut and operational depth while the forward speed was taken as constant. Force F_x, operated at various width of cut found to be increased with an increase in operational depth. At the constant forward speed (2 km/h), 20 cm width of cut when the operational depth was increased from 8 cm to 16 cm the value of F_x was increased from 1080.77 N to 1396.14 N. Shown Figure 1 at a constant forward speed of 2 km/h, a 16 cm operational depth were selected when width of cut was increased from 20 to 40 cm the value of F_x was increased from 1396.14 to 1624.15 N. The action of the ridger resulted in soil accumulation and compression in front point of the ridger to the wings of the ridger hence resulting in higher values of force in x direction as width of cut was increased.

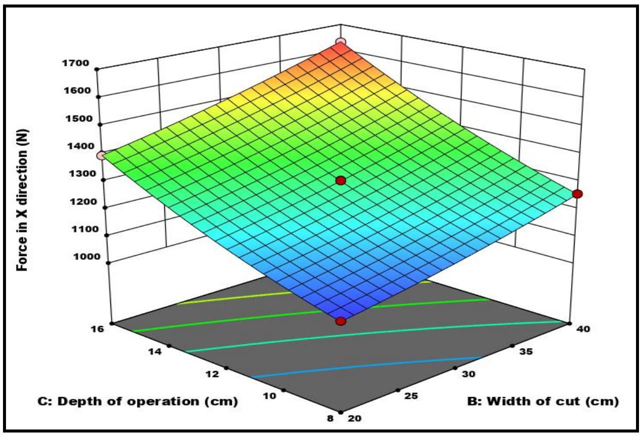

Fig 1: Effect of width of cut and depth of operation on force acting in X direction

3.1.2 Effect of forward speed and width of cut on force acting in x direction

Force F_x, of the ridger, operated at various width of cut found to be significantly increased with an increase in forward speed. At the constant depth (12 cm), 20 cm width of cut when the forward speed was increased from 1.5 to 2.5 km/h the value of F_x was increased from 1141.34 N to 1306.37 N. Although, with all forward speed, the value of F_x was found to be increased with the increased width of cut. According to the Figure 2, a constant operational depth of 12 cm, at 1.5 km/h and 2.5 km/h forward speed were selected when width of cut was increased from 20 to 40 cm the value of F_x was increased from 1141.34 to 1334.55 N at 1.5 km/h and 1306.37 N to 1529.14 N at 2.5 km/h forward speed of test trolly. The action of the ridger resulted in soil tillage and compression in front point of the ridger to the wings of the ridger hence resulting in higher values of force in x direction as width of cut was increased.

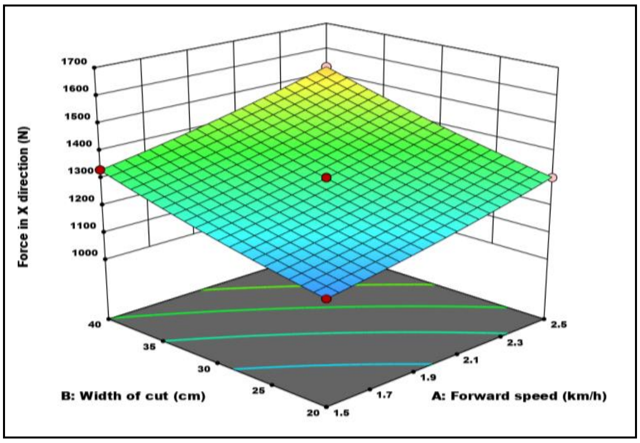

Fig 2: Effect of width of cut and forward speed on force acting in X direction

3.1.3 Effect of forward speed and operational depth on force acting in x direction

At a constant width of cut, the effect of the operational depth and forward speed on the force acting on horizontal direction F_x as shown in the Figure 3 at a constant value of 30 cm width of cut, the maximum value of the F_x was found to be 1619.5 N at 2.5 km/h speed and 16 cm operational depth respectively and minimum value of F_x was 1086.84 N at 1.5 km/h forward speed and 8 cm operational depth respectively. At the constant width of cut, concerning all forward speeds, the value of F_x was found increased with an increase in operational depth. At 1.5 km/h forward speed when the operational depth was increased from 8 to 16 cm the value of F_x was increased from 1086.84 to 1411.21 N. At depth of 8 cm, speed was increased from 1.5 km to 2.5 km/h the value of F_x was increased from 1086.84 to 1244.12 N.

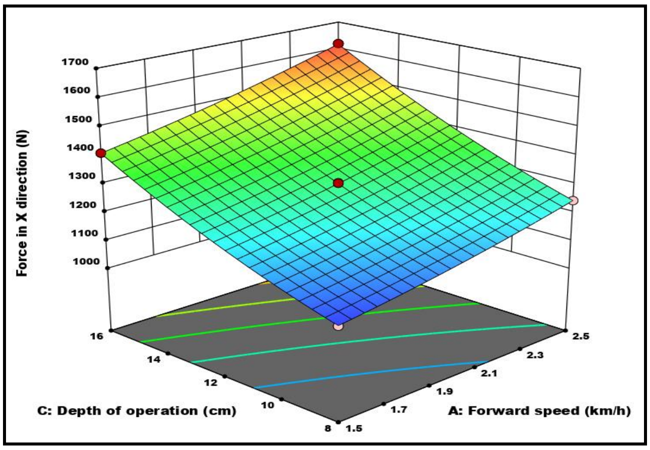

Fig 3: Effect of depth of operation and forward speed on force acting in X direction

3.1.4 Analysis of variance for force acting on ridger in x direction

Analysis of variance was conducted for the force acting on the ridger in x direction, F_x as shown in Table 2. The model F-value of 5267.89 and P value < 0.0001 implies the model is significant at a 99% confidence of interval. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, BC, A^2, B^2, and C^2 are significant ("Prob > F" less than 0.05, $p<0.05$) model terms at a 99.9% (P-value <0.0001) or 95% (P-value <0.05) confidence interval and values that were greater than P-value <0.05 were found to indicate the is non-significant model. For the five replicates of the centre points of the designed experiments, the F-value" of the "Lack of Fit" 0.6633 was not significant (p >0.05) relative to the pure error. Although for the model to be fit, a non-significant lack of fit is good.

The "Pred R^2" of 0.9991 was found to be in reasonable agreement with the "Adj R^2" of 0.9997; i.e. the difference was less than 0.2. "Adeq Precision" is the term to measure the ratio of signal to noise. That ratio was found to be 249.2836, which indicates an adequate signal.

Table 2: ANOVA for force acting in x direction

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3.989E+05	9	44317.58	5267.89	< 0.0001	significant
A-Forward speed	65737.57	1	65737.57	7814.02	< 0.0001	
B-Width of cut	85762.18	1	85762.18	10194.28	< 0.0001	
C-Operational depth	2.415E+05	1	2.415E+05	28702.89	< 0.0001	
AB	218.45	1	218.45	25.97	0.0014	
AC	650.51	1	650.51	77.32	< 0.0001	
BC	881.79	1	881.79	104.82	< 0.0001	
A^2	527.98	1	527.98	62.76	< 0.0001	
B^2	638.88	1	638.88	75.94	< 0.0001	
C^2	2607.53	1	2607.53	309.95	< 0.0001	
Residual	58.89	7	8.41			
Lack of Fit	17.66	3	5.89	0.5711	0.6633	not significant
Pure Error	41.23	4	10.31			
Cor Total	3.989E+05	16				
Std. Dev.	2.90	R^2		0.9999		
Mean	1327.11	Adjusted R^2		0.9997		
C.V.%	0.2186	Predicted R^2		0.9991		
		Adeq Precision		249.2836		

The regression Equation 1 represents the effect of input parameters *viz*. width of cut, operational depth, and forward speed, in the polynomial form given below.

$$\mathbf{F_x}=1304.33+90.65A+103.54B+173.74C+7.39AB+12.75AC+14.85BC+11.20A^2+12.32B^2+24.89C^2 \quad \ldots\text{Eq. (1)}$$

3.2 Effect of experimental parameters on the force acting in vertical direction F_y

Among all experimental runs from table 1, the maximum force acting on the ridger in vertical direction F_y was founded as maximum value, 5553.25 N at a 20 cm width of cut, 16 cm operational depth, and 2 km/h forward speed.

Whereas, the minimum value of the force acting in vertical direction F_y was obtained after analysis the experimental data, the value 2360.8 N found at 8 cm operational depth, 40 cm width of cut, and 2 km/h forward speed.

3.2.1 Effect of width of cut and operational depth on force acting in y direction

Force acting in vertical direction F_y, operated at various width of cut found to be increased with an increase in operational depth. At the constant forward speed (2 km/h), 20 cm width of cut when the operational depth was increased from 8 cm to 16 cm the value of F_y was increased from 3353.5 N to 5553.25 N. It is why? Because when the operational depth of ridger was increasing, the ridger was facing more resistance force during penetration into the soil, causing the higher values of F_y. Although, with all operational depths, the value of F_y was found to be decreased with the increased width of cut. According to the Figure 4, at a constant forward speed of 2 km/h, a 16 cm operational depth were selected when width of cut was increased from 20 to 40 cm the value of F_y was decreased from 5553.25 to 4484.02 N.

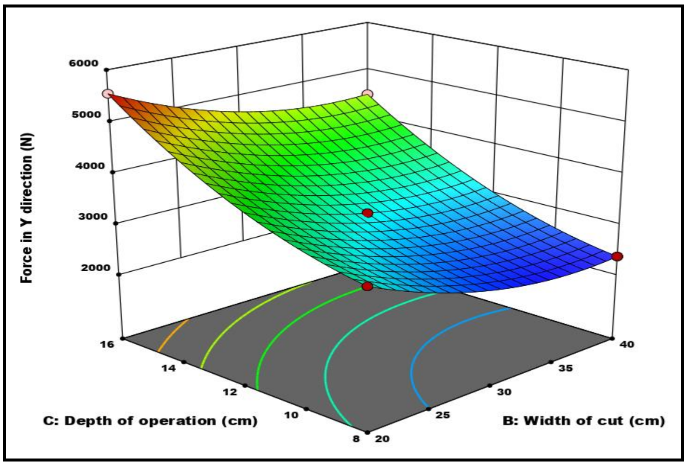

Fig 4: Effect of width of cut and depth of operation on force acting in Y (Vertical) direction

3.2.2 Effect of forward speed and width of cut on force acting in vertical direction F_y

Figure 5 shows that the responses of the force acting in vertical direction F_y on the interactions of two variables width of cut and forward speed while the operational depth was taken as constant variable. At the constant depth 12 cm, 20 cm width of cut when the forward speed was increased from 1.5 to 2.5 km/h the value of F_y was increased from 4134.2 N to 4787.14 N. While, a constant operational depth of 12 cm, at 1.5 km/h and 2.5 km/h forward speed were selected when width of cut was increased from 20 to 40 cm the value of F_y was decreased from 4787.14 N to 3168.05 N at 1.5 km/h forward speed. And 4787.14 N to 3700.98 N at 2.5 km/h forward speed respectively.

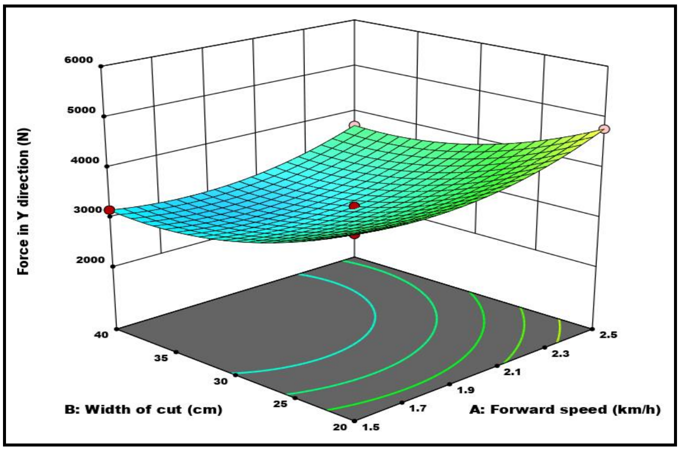

Fig 5: Effect of width of cut and forward speed on force acting in Y direction

3.2.3 Effect of operational depth and speed on force acting in vertical direction F_y

According to the experimental data shown in Table 1 and Figures 6 at a constant value of the 30 cm width of cut, concerning all forward speeds, the value of F_y was found to be significantly increased with an increase in operational depth. As shown in figure 6 at 1.5 km/h speed when the operational depth was increased from 8 cm to 16 cm the value F_y was also found to be increased from 2539.8 to 4703.7 N. Although for the different depths of operation as the forward speed increases the value of the F_y also increased. At depth of 16 cm when speed was increased from 1.5 km to 2.5 km/h at constant value of width of cut 30 cm, the value of F_y was increased from 4703.7 to 5296.2 N.

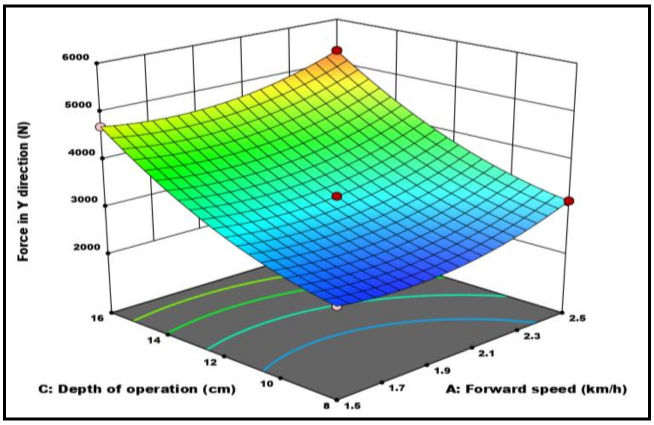

Fig 6: Effect of depth of operation and forward speed on force acting in Y direction

3.2.4 Analysis of variance for force acting in y direction F_y

The model F-value of 155482.79 implies the model is significant shown in Table 3. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, BC, A^2, B^2, and C^2 are significant model terms. Values greater than 0.1000 indicate the model term AC is not significant. There is a 83.76% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good. The predicted R^2 of 0.9987 is in reasonable agreement with the adjusted R^2 of 0.9992; i.e. the difference is less than 0.2. Adeq precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 258.9801 indicates an adequate signal. This model can be used to navigate the design by using Equation 2.

Table 3: ANOVA for force acting on y direction of ridger F_y

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.384E+07	9	1.538E+06	1.555E+05	< 0.0001	significant
A-Forward speed	7.084E+05	1	7.084E+05	71608.67	< 0.0001	
B-Width of cut	2.107E+06	1	2.107E+06	2.129E+05	< 0.0001	
C-Operational depth	9.314E+06	1	9.314E+06	9.414E+05	< 0.0001	
AB	3600.60	1	3600.60	363.94	< 0.0001	
AC	24.01	1	24.01	2.43	0.1632	
BC	1828.85	1	1828.85	184.86	< 0.0001	
A^2	4.976E+05	1	4.976E+05	50295.26	< 0.0001	
B^2	5.562E+05	1	5.562E+05	56222.54	< 0.0001	
C^2	4.763E+05	1	4.763E+05	48138.93	< 0.0001	
Residual	69.25	7	9.89			
Lack of Fit	12.05	3	4.02	0.2808	0.8376	not significant
Pure Error	57.21	4	14.30			
Cor Total	1.384E+07	16				
Std. Dev.	3.15	R^2		0.9997		
Mean	3731.44	Adjusted R^2		0.9992		
C.V.%	0.0843	Predicted R^2		0.9987		
		Adeq Precision		258.9801		

$$F_y = 3240.36 + 297.58A - 513.15B + 1079C - 30AB - 2.45AC - 21.38BC + 343.77A^2 + 363.46B^2 + 336.32C^2 \quad \ldots\text{Eq. (2)}$$

3.3 Effect of experimental variables on ridge height after passing ridger in soil

The height of ridge is an important parameter that is directly related to the functioning of the ridger when it is used as a increasing soil volume, soil bed shaping, and creating furrows and ridges in field. The greater the height of the ridge created by the ridger better will be the shaping of raised and broad soil bed. As shown in the Table 1 among the different experimental runs the maximum ridge height was found 96 mm at 8 cm depth, 30 cm width of cut, 2.5 km/h speed and the minimum height was 46.07 mm at 16 cm depth, 30 cm width of cut, 1.5 km/h speed. The effect of width of cut, operational depth, forward speed on the height of ridge discussed as following.

3.3.1 Effect of width of cut and operational depth on the ridge height

At the constant speed of 2 km/h, the maximum height of the ridge from the unploughed surface were found 89 mm at 40 cm width of cut and 16 cm operational depth and minimum value of ridge height was found 53 mm at 20 cm width of cut and 8 cm operational depth. With all width of cut, the value of ridge height increased with an increase in depth of the operation from 8 to 16 cm. As shown in Figure 7 at a maximum width of cut of 40 cm when operational depth was increased from 8 to 16 cm the height of the ridge was found to be increased from 65 mm to 89 mm. The maximum operational depth 16 cm and a constant speed 2 km/h, and the width of cut were increased from 20 to 40 cm the height of the ridge was found to be increased from 81 mm to 89 mm. Furthermore, the effect of the interaction of width of cut and operational depth on the height of ridge was found to be significant.

3.3.2 Effect of forward speed and width of cut on ridge height

The effect of the width of cut and forward speed of operation on the height of the ridge is shown in Figure 8. At the constant operational depth of 12 cm, the maximum height of the ridge from the unploughed surface were found 86 mm at 40 cm width of cut and 1.5 km/h forward speed and the minimum value was 55 mm at 20 cm width of cut and 2.5 km/h forward speed. With all width of cuts, the value of ridge height, was found decreases with an increase in forward speed of the operation from 1.5 km/h to 2.5 km/h. The height of the ridge was found decreased from 86 mm to 66 mm at 40 cm width of cut. Although for the different forward speeds the value of the ridge height was found to be increases when the width of cut increases. At 2.5 km/h forward speed, and the width of cut was increased from 20 cm to 40 cm the height of the ridge was found to be increased from 55 mm to 66 mm.

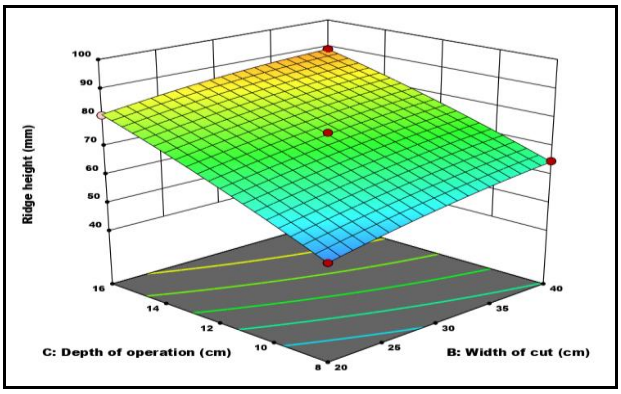

Fig 7: Effect of width of cut and depth of operation on height of ridge

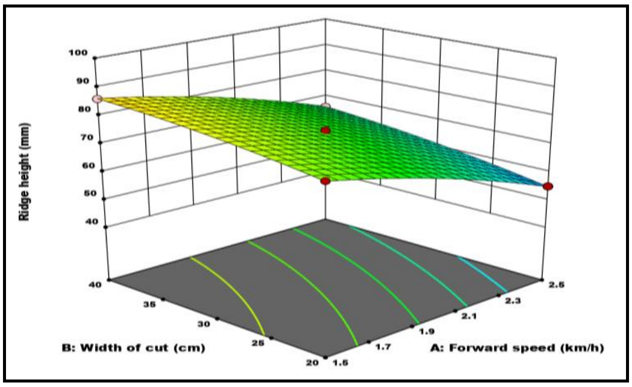

Fig 8: Effect of width of cut and forward speed on height of ridge

3.3.3 Effect of forward speed and operational depth on the ridge height

At the constant width of cut 30 cm, the maximum height of the ridge from the unploughed surface were found to be 96 mm at 1.5 km/h speed and 16 cm operational depth whereas the minimum value was 48 mm at 2.5 km/h speed and 8 cm operational depth. With all speeds, the value of ridge height was found to be significantly increased with an increase in depth of the operation from 8 cm to 16 cm. As shown in Figure 9 at 2.5 km/h speed when depth is increased from 8 cm to 16 cm the height of the ridge was found to be increased from 48 mm to 73 mm. Although for the different operational depths the value of the ridge height was found to be decreases when the forward speed is increases. At 16 cm operational depth, the forward speed was increased from 1.5 to 2.5 km/h the height of the ridge was found to be decreased from 96 mm to 73 mm.

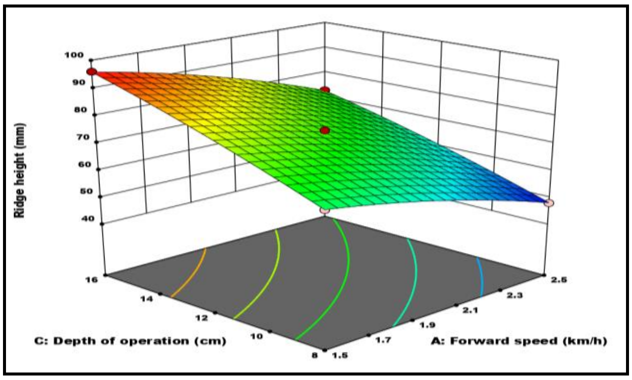

Fig 9: Effect of depth of operation and forward speed on height of ridge

3.3.4 Analysis of variance for ridge height of the ridger

The model F-value of 1358.39 implies the model is significant. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, BC, A^2, B^2, C^2 are significant model terms shown in Table 4. The Lack of Fit F-value of 0.28 implies the Lack of Fit is not significant relative to the pure error. Non-significant lack of fit is good. The Predicted R^2 of 0.9977 is in reasonable agreement with the Adjusted R^2 of 0.9987; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 136.793 indicates an adequate signal. This model can be used to navigate Equation 3 of the design space.

Table 4: ANOVA for the ridge height of the ridger

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2532.43	9	281.38	1358.39	< 0.0001	significant
A-Forward speed	924.50	1	924.50	4463.10	< 0.0001	
B-Width of cut	190.13	1	190.13	917.84	< 0.0001	
C-Operational depth	1378.13	1	1378.13	6653.02	< 0.0001	
AB	2.25	1	2.25	10.86	0.0132	
AC	2.25	1	2.25	10.86	0.0132	
BC	4.00	1	4.00	19.31	0.0032	
A²	16.01	1	16.01	77.29	< 0.0001	
B²	6.06	1	6.06	29.27	0.0010	
C²	6.06	1	6.06	29.27	0.0010	
Residual	1.45	7	0.2071			
Lack of Fit	0.2500	3	0.0833	0.2778	0.8395	not significant
Pure Error	1.20	4	0.3000			
Cor Total	2533.88	16				
Std. Dev.	0.4551	R²		0.9994		
Mean	72.35	Adjusted R²		0.9987		
C.V.%	0.6290	Predicted R²		0.9977		
		Adeq Precision		136.7927		

Ridge height = $74.40-10.75A + 4.88B + 13.13C + 0.7500AB-0.7500AC-1.0BC-1.95A^2-1.20B^2-1.20C^2$ …Eq.(3)

3.4 Post analysis of the optimised values

After analysis we achieved point predictions by configuring the desired operating conditions within the software, and subsequently determining the predicted response with a 95% confidence interval. Table 5 displays the model's predictions for the optimized independent parameters. To validate these predicted values, experiments were conducted under the optimal operating conditions. The results of these experiments served to confirm the accuracy of the optimized parameters and the performance of the hoe-type ridger. The horizontal force (F_x), vertical force (F_y), and ridge height were measured at 1353.57 N, 2731.21 N. and 67.28 mm, respectively, as opposed to the predicted values of 1307.4 N, 3223.14 N, and 74.88 mm, with a desirability of 0.619 and 95% confidence interval (CI).

Table 5: Optimised solution by Box-Behnken Design technique

Number	Forward speed km/h	Width of cut cm	Operational depth (cm)	Force in X direction N	Force in Y direction N	Ridge height mm	Desirability	
1	**2.172**	**40.000**	**9.727**	**1353.570**	**2731.217**	**67.281**	**0.619**	**Selected**
2	2.172	40.000	9.732	1353.748	2731.944	67.296	0.619	
3	2.170	39.998	9.763	1354.609	2735.122	67.442	0.619	
4	2.176	39.998	9.706	1353.475	2731.735	67.121	0.619	
5	2.179	39.999	9.750	1355.974	2742.689	67.189	0.619	
6	2.163	39.999	9.748	1352.696	2725.973	67.542	0.619	
7	2.195	39.998	9.852	1363.404	2777.176	67.168	0.618	

4. Conclusion

To evaluate the designed parameter of performance for hoe type ridger in vertisol soil under controlled soil bin condition and analyse the data by using Box-Behnken Design of Surface Response Method (RSM) technique, and the result was obtained from RSM. The best combination of all dependent and independent variables was found after analysis the data in software the value of F_x was 1353.57 N, Force of F_y 2731.21 N, and the ridge height was 67.28 mm at 2.17 km/h forward speed, 40 cm width of cut, and 9.72 cm operational depth at 95% confidence of interval and the model shows significant.

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The contribution of all author for this research article is equal. All the research work has done under the supervision of A.K. Shrivastava and D.M. Kadam in the College of Agricultural Engineering, JNKVV, Jabalpur. Author Avinash Kumar, Yalaka Nandini, Rohit Namdeo and Indraveer Singh completed all experiments in laboratory and prepare and edited this manuscript. The manuscript corrected by Atul Kumar Shrivastava, Anil R. Pimpale and Dhananjay M. Kadam. There is no any area of conflict by any funding agency involved in this research work.

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