

Performance evaluation of different shape and orientation of digging blades in soil bin

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Received: 04 February 2025; accepted: 21 April 2025

This research has optimized the shape of digging blade with the relationship between speed, rake angle and depth. The effect of speed, rake angle and depth of blades (triangular fork, V shape, convex and rectangular) on drafts has studied experimentally for the speed (2.06, 2.9 and 4.18 km/h), rake angle (15°, 20°, 25°) and depth of operation (10, 15, 20 cm) in a soil bin. The study has conducted in the soil bin to finalize the design of digger blades for minimum draft for the root zone depth of turmeric and ginger crops. Response surface methodology (RSM), a mathematical modelling technique has used for design experiments, statistical evaluation, and optimization of parameters. The mean values of the vertical and horizontal draft at different forward speed and depth of operation have increased with the increase in the rake angle of all four types of blades in the soil bin. The average minimum vertical draft has found to be 2.167, 2.987, 5.867 and 4.057 kgf at 15° rake angle and maximum of 26.967, 26.527, 42.473 and 89.533 kgf at 25° rake angle for triangular fork, V-shape, convex, and rectangular shape of blades, respectively. The average minimum horizontal draft has found to be 58.36, 59.317, 65.95, and 38.71 kgf at 15° rake angle and maximum of 153.517, 170.943, 183.82 and 241.67 kgf at 25° rake angle for V-shape, convex, rectangular and triangular fork shape of blades, respectively. The overall mean draft has found to be maximum in triangular fork shape blade and minimum in V-shape blade which can be used for performance evaluation of the digger in the field.

Keywords: Angle, Blade, Draft, Shape

1 Introduction

India holds the seventh position in ginger export worldwide, however is the "largest producer of ginger in the world"¹⁰. The global production of turmeric is around 11 lakh tonnes per annum. India dominates the world production scenario contributing 80% followed by China (8%), Myanmar (4%), Nigeria (3%) and Bangladesh (3%). In 2022-23, India had exported 1.70 lakh tonnes of turmeric compared to 1.53 lakh tonnes in the previous year (Turmeric outlook, 2024). The area under ginger in north-east region is 30.84 thousand ha which gives total production of 209.15 thousand tonnes at an average yield of 6.78 t/ha against the national productivity of 3.56 t/ha. The production of ginger is highest in Meghalaya followed by Mizoram and Arunachal Pradesh. However, the productivity is highest in Manipur (9.86 t/ha) followed by Nagaland (9.05 t/ha) and Arunachal Pradesh. The area under turmeric in the region is 17.27 thousand ha with a total production of 32.36 thousand tonnes. The productivity of the crop is much lower (1.87t/ha) compared to the national productivity of 3.47 t/ha⁵.

Traditional techniques need additional labour and have limited field capacity, leading to higher production costs⁸. Manual digging can cause bruising and damage to rhizomes, affecting both their quality and price on the market. Farmers lack skills in using machines for turmeric production, notably during planting and harvesting operations. The harvester requires a digging blade and soil separator and root collection equipment to be fully functional. It may be more effective and advantageous for farmers if a suitable system could be created for extracting the soil that contains rhizomes and gathering them.

The farmers are planting turmeric and ginger on planted beds. Prepare turmeric beds measuring 20-30 cm tall and 75-100 cm broad, with a minimum gap of 30 cm between two rows¹⁷. For moistened crops, prepare ridges and furrows and plants seedlings at the top of the bed. With these in view, the investigation envisaged to develop a suitable mini tractor operated turmeric harvester to dig out and collect the turmeric rhizome. It was observed that plant the mother rhizome or finger rhizome in raised cultivation beds measuring 60 cm to 90 cm width and 15 cm height on

ridges and furrows or on a flat system⁹. The spacing is 30 cm × 15 cm or 30 cm × 20 cm (in beds), 40-60 cm × 25 cm (on ridges and furrows), and 60 cm × 15 cm (in flat system). The tractor mounted turmeric digger was developed with the blade length of 60 cm and working depth of 18-20 cm¹⁵. The moisture content of the Erode local was 82 per cent (wb) and bulk density was varied from 753 to 801 kg/m³ at the moisture range of 10 to 70 per cent(wb), respectively¹.

2 Materials and Methods

Four different shapes of digging blades were tested in the Soil Dynamics Research Laboratory at the Central Institute of Agricultural Engineering (CIAE), Bhopal under controlled soil bin conditions for the evaluation of these performances. The study was conducted in the soil bin to finalize the design of digger blades for minimum draft for the root zone depth of turmeric and ginger crops. Based on the soil parameters for digging the crop in the field, the laboratory soil was proposed to simulate the field condition for testing of these four blades. The experiment was conducted using an indoor soil bin that is available at Agricultural Mechanization Division, Central Institute of Agricultural Engineering (CIAE), Indian Council of Agricultural Research, Bhopal, Madhya Pradesh, India. The soil bin system as shown in Fig. 1 consists of stationary soil bin unit, moveable carriage unit, soil processing unit, and instrumentation and data acquisition unit (DAQ) system.

2.1 Construction of soil bin

The soil bin was made of cement concrete and brick structures with overall dimension of 16.0 x 2.5 x 1.0 m, which holds enough soil volume to facilitate testing of the equipment without side effects and variability. Lengthwise sidewalls of the soil bin were reinforced

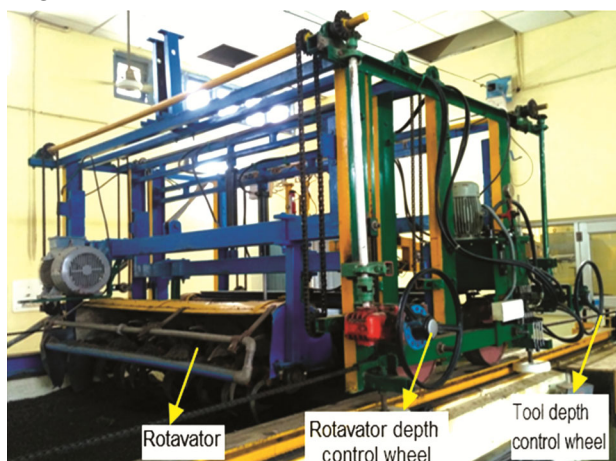


Fig. 1 — Indoor soil bin.

with I-beams to facilitate movement of carriage. The I-beam used for railway track were reinforced in the side walls in an inverted position to that of a railway track, i.e. the faces of the flat face of beam upside and the curved face anchored. On the shorter (width) sidewalls, chain-sprocket drive systems have been mounted, which provides motion to the carriage. Soil having composition varying from sand to clay can be filled in the bin, as per requirement. On either end of both –beams, limit and stop switches were provided. Limit switches facilitate auto-reversing and stop switches prevent any accidental situation in case the limit switches fail to activate auto-reversing mechanism. The soil of desired characteristics required for conducting the experiment was filled in the soil bin¹⁴.

2.1.1 Characteristics of soil in soil bin

The black soil of Central Institute of Agricultural Engineering (CIAE) was characterized as clay loam having structure as 'sub-angular' blocky. In the experimental fields of soil bin, the basic physical properties of the soil were given in Table 1.

2.1.2 Toolbar carriage

The carriage contains two tool bars, a front and a rear as shown in Fig.1. The front tool bar can be used for mounting the experimental tool and the rear for attaching the soil processing gadgets. Each tool bar is equipped with steering wheel and chain sprocket drive to raise, lower and lock them at desired position. With this arrangement, depth of operation of each tool bar can be manually changed and maintained. To set the depth of operation to a desired value, independent depth maintaining arrangement was provided for both tool bars. Four side wheels are also provided on the carriage, which are always in contact with the guide rail (I-beam) to counter any side and up thrust. Drive to carriage was provided through two chain sprocket drives provided on either side on two I-beams. A driving shaft containing large sprocket, which gets drive from 15 kW automatic variable speed (AVS) drive, drives the chain sprocket system to provide motion to the carriage. The carriage can be accelerated by the drive system to the speed equivalent to the field operational speed of different

Table 1 — Physical properties of the soil in soil bin.

Properties	Values
Soil texture	Clay loam
Particle size distribution	
Sand (20-2000 μm), %	41.50
Silt (2-20 μm), %	25.20
Clay (< 2 μm), %	33.30
Soil bulk density, g/cm ²	1.84



Fig. 2 — Different shape of blade attached with the mounting unit in soil bin (a) V shape, (b) triangular fork, (c) convex and (d) rectangular.

implements. The speed of the carriage can be varied by varying rpm of AVS drive. On both sides of I-beam in the soil bin, limit switches and stop switches are provided to stop and change the direction of motion of the tool carriage unit automatically¹².

2.1.3 Soil preparation

Soil preparation includes the tilling, wetting of soil, levelling and packing of the soil. This unit has roto-tiller, soil leveller, roller for compaction and water application system to obtain uniform moisture and penetration resistance throughout each experiment.

2.1.4 Water application system

Uniformity of soil moisture was essential to obtain even compaction. The soil was wetted with the hose pipe initially and later on with a spray boom attached to the carriage. The system consists of 1000 liters overhead tank, 1 hp self-priming pump and a frame of pipe to discharge water through uniformity spaced perforations. The frame of pipe having connected to pump was mounted on the carriage and with the movement of carriage; water was applied uniformly at a rate of 20 l/min.

2.1.5 Roto-tiller

A roto-tiller mounted on the carriage was used to till the soil. It was powered by a 7.5 kW advanced variable speed drive mounted on it. The tiller was 1.90 m wide and attached to the front of the toolbar carriage. It consists of 47 number of C shape blade to till the soil to varying depth. Two passes were made and uniform soil tilling throughout the width and length of the soil bin.

2.1.6 Levelling unit

The soil was levelled initially with the levelling unit attached to the carriage unit. The roto-tiller and levelling unit should work simultaneously. Therefore, a 2270 mm wide and 420 mm long scraper was attached behind the roto-tiller unit. The height of the scraper can be adjusted up to 350 mm with a two-way hydraulic pump.

2.1.7 Soil packing

Soil packing was an important phase of soil preparation. A plain roller of 1680 mm wide and 1130 mm diameter was attached to the tool carriage unit behind the scraper. The height of the roller was adjusted up to 450 mm with a hydraulic system. The number of passes of the roller was desired according to the compaction of the soil in the field.

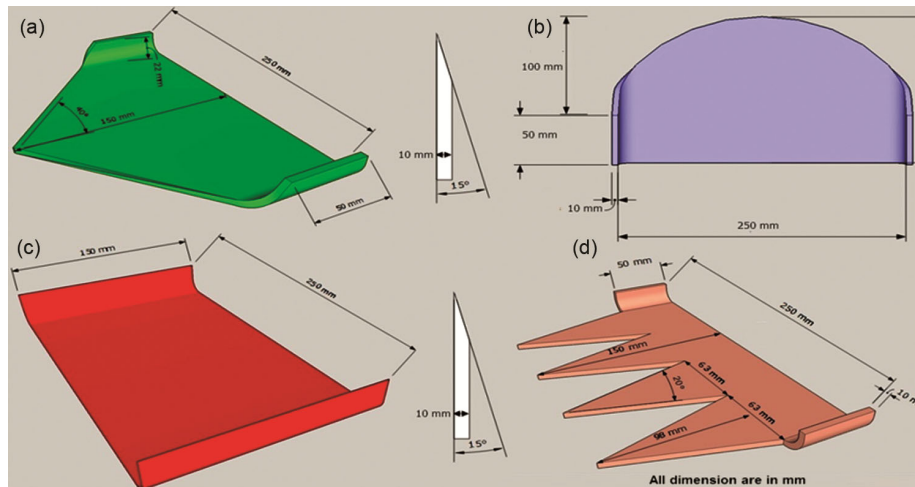


Fig. 3 — Schematic view of different shape of blade for turmeric and ginger harvesting (a) V shape, (b) convex, (c) rectangular and (d) triangular fork.

Table 2 — Plan of experiment in the soil bin.
Independent

	Levels		
Speed (S), km/hr	S1- 2.06	S2- 2.90	S3- 4.18
Rake angle/Angle of blade(A), Degree	A1-15°	A2-20°	A3- 25°
Depth (D), cm	D1-10	D2-15	D3-20
Dependent			
Vertical draft, kgf			
Horizontal draft, kgf			
SP1-Triangular fork, SP2-V-shape, SP3-Convex and SP4-Rectangular.			

2.2 Test procedure for the experiment in the laboratory

The test was conducted in the soil bin, by changing the different shape of the blade (Fig. 2 and Fig. 3) as per the plan of the experiment (Table 2). The observation of the horizontal and vertical draft was recorded for each test run. The test run was replicated thrice to remove any experimental bias. In the experiment, the test set up was planned by changing the four different shape of blade and varying the speed (2.06, 2.9 and 4.18 km/h), rake angle (15°, 20°, 25°) and depth of operation (10, 15, 20 cm) of the blade and observation of draft were recorded for each test run and their replications¹³. The moisture content of the soil in the soil bin was tried to maintain 10-13 per cent and approximately 850-1200 kPa cone index as in the field at the time of digging of the turmeric and ginger crop³.

2.3 Design of experiment

A design expert software was used with the different levels of independent and dependent variables as given in Table 2. The independent variable of the experiment was selected as per the recommendation of different researchers as given below:

The different shapes of the blade were tested in the soil bin as per the different treatment combination. The laboratory set was prepared to attach or detach the different blades as shown in Fig. 2 and Fig. 4. The provision was made in the blade mounting unit to vary the angle of the blade. The depth of operation of the blade can be maintained from zero to the different depth of the soil by lowering the blade mounting unit through the wheel given besides the carrier unit. The moisture content of the soil in the soil bin was tried to maintain 10-13 per cent as in the field at the time of digging of the turmeric and ginger crop. The mounting unit consisted of a pair of flats of size 550x110x25 mm, provision for mounting the blades and guides on both sides to restrict the soil movement from the blade to the rear was mounted on the behind of the too carriage unit. The unit attached to a standard fabricated using a 60 mm square M. S. section of the tool carriage unit. The upper end of both the flats was bolted to the standard at a distance of 250 mm with an L shape flat of 8 mm.

2.4 Statistical analysis

The experiment was carried out as per the layout of experiments described for soil bin. The soil bin

experiment was carried out in Response surface methodology (RSM) statistics design. The observation of different variables was collected and analysed by using SAS statistical software(IBM Corporation, New York, USA). Response surface methodology (RSM), a mathematical modelling technique was used for design experiments, statistical evaluation, and optimization of process parameters. The data collected for different variables were processed and analysed by the method of analysis of variance (ANOVA). The ANOVA tables

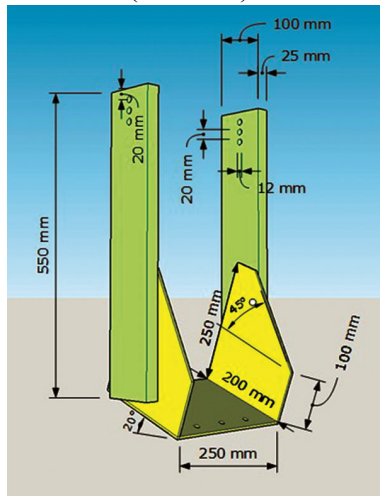


Fig. 4 — Attachment unit for different types of blade.

were drawn for critical differences at 5% and 1% level of significance. Here, optimal customized design experiment was employed at three controlled conditions such as angle of blade, speed, and depth for 20 experiments. The complete design model with test results were used for determining vertical draft (VD) and horizontal draft (HD) are presented in Table 3. Based on the experimental results, the relationship between actual and predicted responses are shown in Fig. 5.

3 Results and Discussion

The effect of independent parameters such as angle of blade (°), speed (km/h), and depth (mm) for different blade shape (triangular fork, V shape, convex and rectangular) were assessed by running 20 experimental trials of optimal customized design. The obtained results for vertical draft and horizontal draft are listed shown in Table 3. The statistical analysis of variance (ANOVA) was carried out for finding out the significance of the regression model, p-values, F-values, signal-noise ratio, and lack of fit. The obtained ANOVA results are presented in Table 4. By using the coefficient R^2 and adjusted R^2 the accuracy of model in relation to the experimental outcomes was determined. The effect of parameters on responses was also studied by using 3D contour plots. The obtained p

Table 3 — Mean values of vertical draft and horizontal draft of different shape of blades.

Sr. No.	Angle of blade Degree	Speed km/h	Depth mm	Triangular fork		V-shape		Convex		Rectangular	
				VD kgf	HD kgf	VD kgf	HD kgf	VD kgf	HD kgf	VD kgf	HD kgf
1	20	4.18	100	3.117	110.920	19.957	102.637	19.957	122.637	38.477	143.770
2	15	4.18	200	25.520	97.531	13.460	169.697	42.473	149.997	18.987	140.543
3	25	4.18	100	15.920	143.373	25.813	76.557	22.900	125.247	40.387	151.657
4	20	2.80	200	19.520	106.880	11.783	122.630	25.287	148.393	25.120	144.350
5	25	4.18	150	22.947	150.407	26.527	148.660	34.003	133.937	43.900	164.120
6	20	4.18	150	10.523	146.160	23.610	156.637	35.240	131.750	41.807	160.000
7	25	4.18	200	26.967	153.517	22.123	170.943	40.903	183.820	89.533	241.670
8	20	2.80	200	23.060	124.127	21.510	144.033	26.463	144.720	43.277	189.070
9	25	2.80	150	22.047	134.407	24.527	120.960	18.003	102.937	42.170	164.120
10	20	4.18	150	11.923	121.160	19.610	135.637	20.240	130.750	41.807	160.000
11	15	4.18	150	8.855	124.423	18.027	115.607	19.987	132.753	15.987	137.543
12	15	2.06	150	8.167	58.360	4.010	59.317	5.867	106.830	4.057	52.810
13	25	2.06	200	8.960	120.503	19.827	85.027	18.707	120.380	25.190	67.287
14	20	2.06	150	7.693	57.563	5.043	71.623	10.240	106.833	13.427	57.873
15	20	2.8	200	19.420	116.880	12.783	95.630	20.287	148.393	23.120	114.350
16	25	2.06	100	2.237	64.377	8.003	53.683	15.343	68.497	21.703	52.740
17	25	2.80	150	14.853	98.900	16.677	98.833	26.550	127.983	33.920	109.787
18	15	2.80	100	1.967	60.977	6.947	69.670	10.613	73.290	7.173	80.910
19	20	2.06	100	2.167	62.590	2.987	40.520	9.253	65.950	3.313	38.710
20	25	2.80	150	14.853	98.900	15.677	118.833	27.550	127.983	33.920	109.787

VD- Vertical draft, HD- Horizontal draft

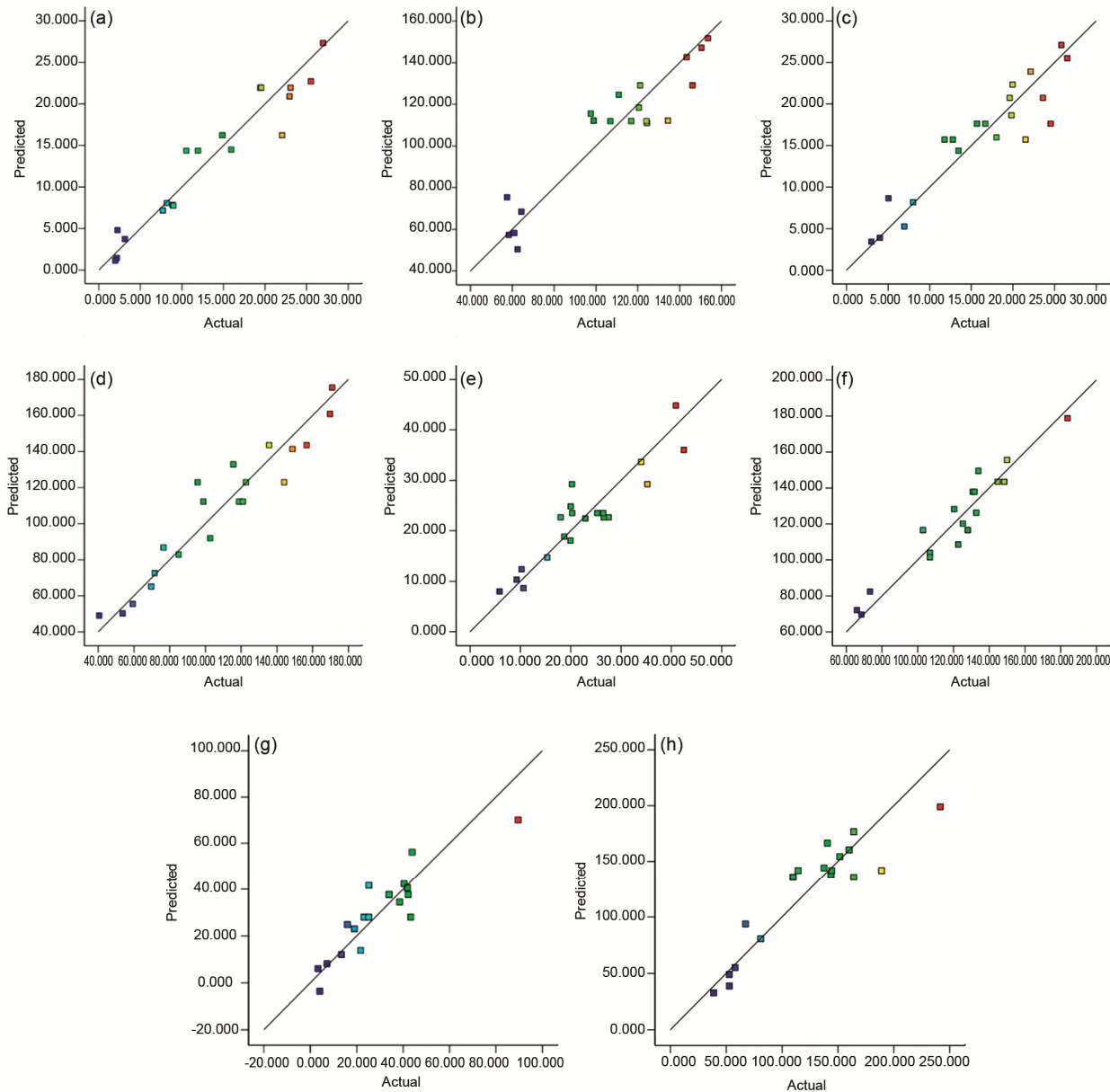


Fig. 5 — Relationship between actual and predicted values (a) vertical draft of triangular fork, (b)horizontal draft of triangular fork, (c) vertical draft of V shape, (d) horizontal draft of V shape, (e) vertical draft of convex shape, (f) horizontal draft of convex shape, (g) vertical draft of rectangular shape, and (h) horizontal draft of rectangular shape.

values by using F- test regression model was found very less (<0.0001) indicating that the chosen models were of high significance. All the values of regression coefficients with the significance levels are presented in Table 5. The adequate precision values determine the signal-noise ratio and a value greater than 4 is considered as acceptable. Therefore, the model can be used to navigate the design space.

3.1 Effect of angle of blade and depth on vertical draft of triangular fork shape blade

The average values of the vertical draft at different angle of blade and depth of operation of triangular fork shape blade as shown in Table 3. From Fig 6a it can be observed that as the angle of blade increased from 15 to 25° and depth increased from 100 to 200 mm of tool carrier unit of soil bin, the vertical draft increased from 2.167 to 26.967kgf. The highest vertical

Table 4 — Anova model and lack of fit.					
Source	Sum of Squares	df	Mean Square	F-value	p-value
<i>Triangular fork blade</i>					
Vertical draft (VD, kgf)					
Model	1175.00	7	167.86	20.74	< 0.0001
A-Angle of blade	85.79	1	85.79	10.60	0.0069
B-Speed	142.93	1	142.93	17.66	0.0012
C-Depth	621.76	1	621.76	76.82	< 0.0001
AC	89.94	1	89.94	11.11	0.0060
B ²	87.14	1	87.14	10.77	0.0066
Lack of Fit	53.04	7	7.58	0.8595	0.5882
Horizontal draft (HD, kgf)					
Model	17079.45	4	4269.86	24.64	< 0.0001
A-Angle of blade	3554.03	1	3554.03	20.51	0.0004
B-Speed	9683.19	1	9683.19	55.87	< 0.0001
C-Depth	2375.95	1	2375.95	13.71	0.0021
BC	744.93	1	744.93	4.30	0.0458
Lack of Fit	1296.62	10	129.66	0.4976	0.8374
<i>V shape blade</i>					
Vertical draft (VD, kgf)					
Model	913.67	4	228.42	22.32	< 0.0001
A-Angle of blade	246.36	1	246.36	24.07	0.0002
B-Speed	489.75	1	489.75	47.85	< 0.0001
C-Depth	36.04	1	36.04	3.52	0.0802
BC	82.98	1	82.98	8.11	0.0122
Lack of Fit	41.27	10	4.13	0.1839	0.9887
Horizontal draft (HD, kgf)					
Model	26336.85	9	2926.32	11.62	0.0003
B-Speed	13677.03	1	13677.03	54.32	< 0.0001
C-Depth	6816.58	1	6816.58	27.07	0.0004
BC	1277.57	1	1277.57	5.07	0.0480
Lack of Fit	822.71	5	164.54	0.4853	0.7768
<i>Convex shape blade</i>					
Vertical draft (VD, kgf)					
Model	1651.15	4	412.79	20.71	< 0.0001
A-Angle of blade	210.22	1	210.22	10.55	0.0054
B-Speed	951.79	1	951.79	47.75	< 0.0001
C-Depth	479.35	1	479.35	24.05	0.0002
BC	148.18	1	148.18	7.43	0.0156
Lack of Fit	109.90	10	10.99	0.2906	0.9544
Horizontal draft (HD, kgf)					
Model	14851.00	4	3712.75	40.63	< 0.0001
A-Angle of blade	227.84	1	227.84	2.49	0.1352
B-Speed	4265.70	1	4265.70	46.68	< 0.0001
C-Depth	9207.42	1	9207.42	100.76	< 0.0001
AB	385.77	1	385.77	4.22	0.0578
Lack of Fit	942.98	10	94.30	1.10	0.4867
<i>Rectangular shape blade</i>					
Vertical draft (VD, kgf)					
Model	5848.79	4	1462.20	16.11	< 0.0001
A-Angle of blade	2734.93	1	2734.93	30.13	< 0.0001
B-Speed	2676.95	1	2676.95	29.50	< 0.0001
C-Depth	373.81	1	373.81	4.12	0.0605
AC	341.19	1	341.19	3.76	0.0716
Lack of Fit	1069.35	10	106.93	1.83	0.2617
Horizontal draft (HD, kgf)					
Model	14851.00	4	3712.75	40.63	< 0.0001
A-Angle of blade	227.84	1	227.84	2.49	0.1352
B-Speed	4265.70	1	4265.70	46.68	< 0.0001
C-Depth	9207.42	1	9207.42	100.76	< 0.0001
AB	385.77	1	385.77	4.22	0.0578
Lack of Fit	942.98	10	94.30	1.10	0.4867

Table 5 — Anova fit statistics.

Term	<i>Triangular fork blade</i>		<i>V shape blade</i>		<i>Convex shape blade</i>		<i>Rectangular shape blade</i>	
	VD	HD	VD	HD	VD	HD	VD	HD
Mean	13.54	107.60	15.95	107.86	22.29	122.65	9.53	124.05
Coefficient of determination (R^2)	0.9237	0.8679	0.8562	0.9127	0.8467	0.9155	0.8112	0.8343
Adjusted R^2 (Adj R^2)	0.8791	0.8327	0.8178	0.8342	0.8058	0.8930	0.7608	0.7901
Standard deviation (Std. Dev.)	2.84	13.16	3.20	15.87	4.46	9.56	9.53	24.26
Coefficient of variance (C. V.)	21.02	12.24	20.06	14.71	19.85	7.79	31.38	19.56
Adequate Precision (A. P.)	14.554	15.389	14.8004	11.2720	16.4976	22.8351	15.4764	13.7064

VD- Vertical draft, HD- Horizontal draft

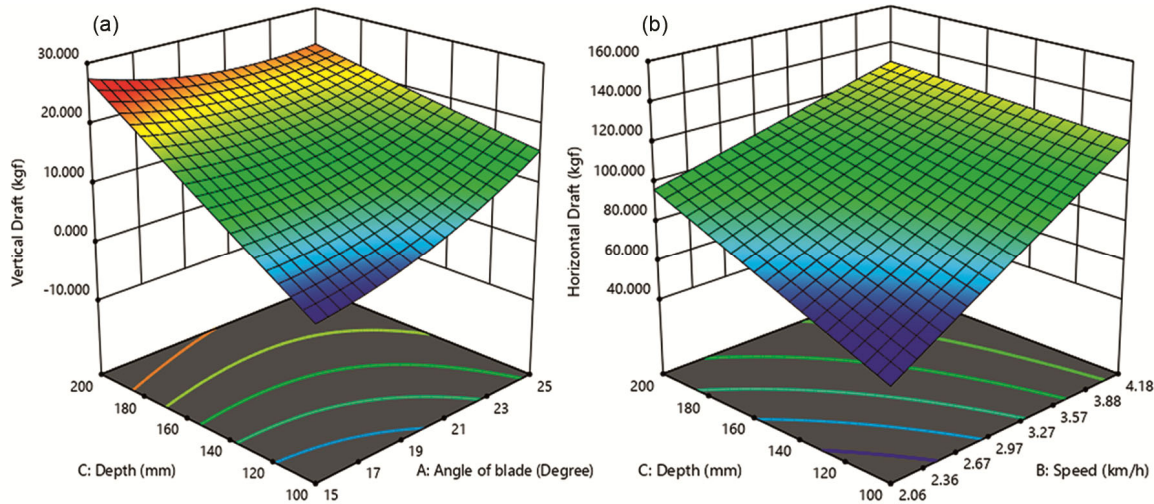


Fig. 6 — (a) Effect of angle of blade and depth on vertical draft and (b) Effect of speed and depth on horizontal draft using triangular fork blade.

draft 26.967kgf was observed at angle of blade 15° and depth 200 mm, whereas the lower horizontal draft 2.167kgf was recorded for angle of blade 15° and depth 100 mm, respectively.

3.2 Effect of speed and depth on horizontal draft of triangular fork shape blade

The average values of the horizontal draft at different forward speed and depth of operation of triangular fork shape blade as shown in Table 3. From Fig 6b it can be observed that as the depth increased from 100 to 200 mm for forward speed of tool carrier unit of soil bin increased from 2.06 to 4.18 km/h, the horizontal draft increased from 58.36 to 153.517 kgf. The highest horizontal draft 153.517 kgf was observed at speed 4.18 km/h and depth 200 mm, whereas the lower horizontal draft 58.36 kgf was recorded for speed 2.06 km/h and depth 100 mm, respectively.

3.3 Effect of speed and depth on vertical draft of V shape blade

The average values of the vertical draft at different speed and depth of operation of V shape blade as shown in Table 3. From Fig 7a it can be observed that as the speed increased from 2.06 to 4.18 km/h and depth increased from 100 to 200 mm of tool carrier unit of soil bin, the vertical draft increased from 2.987 to 26.527kgf. The highest vertical draft 26.527kgf was observed at speed 4.18 km/h and depth 100 mm, whereas the lower vertical draft 2.987kgf was recorded for speed 2.06 km/h and depth 150 mm, respectively.

3.4 Effect of speed and depth on horizontal draft of V shape blade

The average values of the horizontal draft at different forward speed and depth of operation of V shape blade as shown in Table 3. From Fig 7b it can

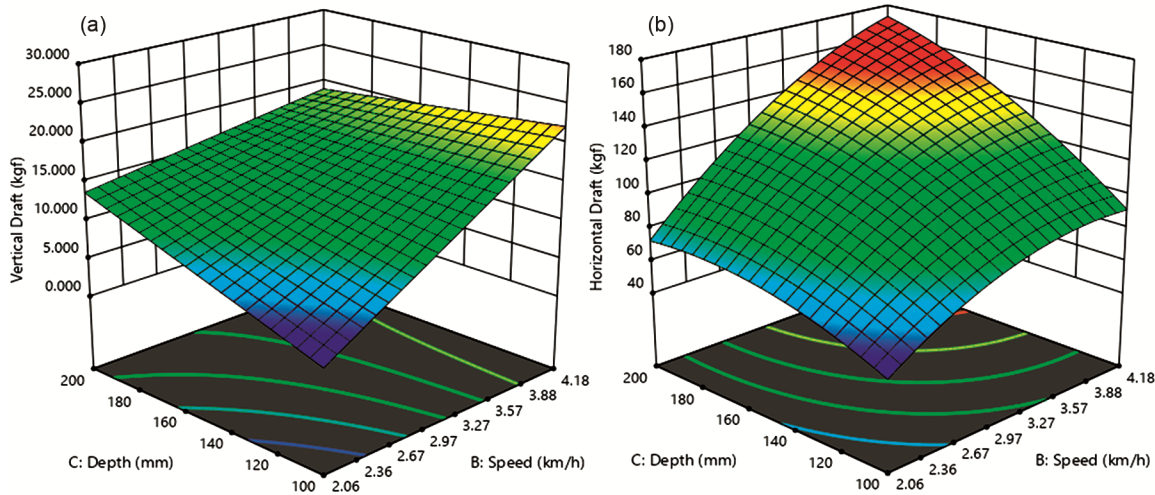


Fig. 7 — (a) Effect of speed and depth on vertical draft and (b) Effect of speed and depth on horizontal draft using V shape blade.

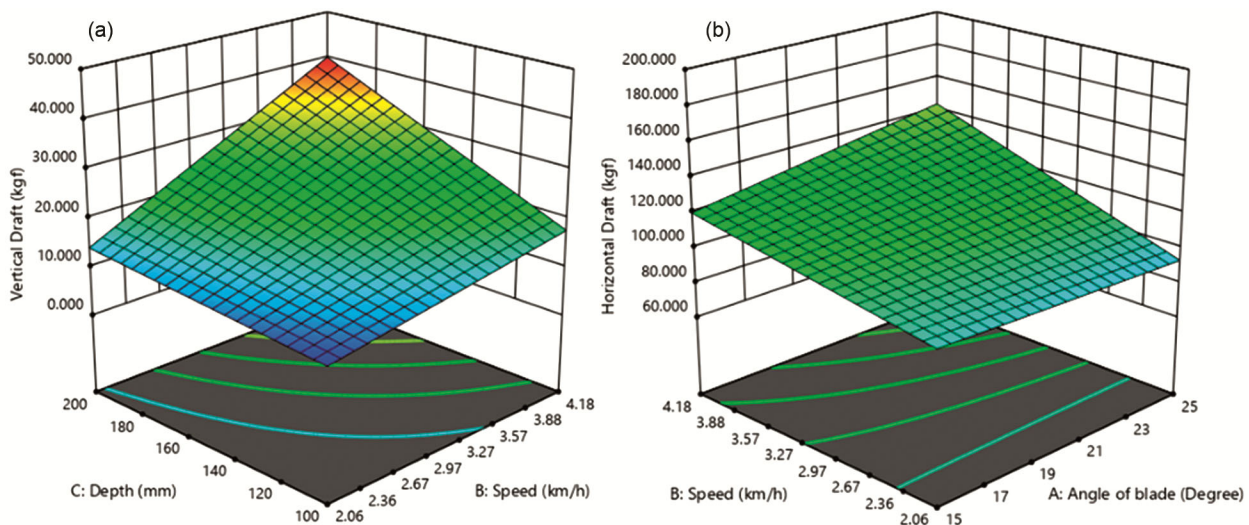


Fig. 8 — (a) Effect of speed and depth on vertical draft and (b) Effect of angle of blade and speed on horizontal draft using convex shape blade.

be observed that as the depth increased from 100 to 200 mm and forward speed of tool carrier unit of soil bin increased from 2.06 to 4.18 km/h, the horizontal draft increased from 59.317 to 170.943kgf. The highest horizontal draft 170.943kgf was observed at speed 4.18 km/h and depth 200 mm, whereas the lower horizontal draft 59.317kgf was recorded for speed 2.06 km/h and depth 100 mm, respectively.

3.5 Effect of speed and depth on vertical draft of convex shape blade

The average values of the vertical draft at different forward speed and depth of operation of convex shape blade as shown in Table 3. From Fig 8a it can be observed that as the depth increased from 100 to 200 mm and forward speed of tool carrier unit of soil

bin increased from 2.06 to 4.18 km/h, the vertical draft increased from 5.867 to 42.473kgf. The highest vertical draft 42.473kgf was observed at speed 4.18 km/h and depth 200 mm, whereas the lower vertical draft 5.867kgf was recorded for speed 2.06 km/h and depth 100 mm, respectively.

3.6 Effect of angle of blade and speed on horizontal draft of convex shape blade

The average values of the horizontal draft at different angle of blade and speed of operation of convex shape blade as shown in Table 3. From Fig 8b it can be observed that as the angle of blade increased from 15 to 25° and forward speed of tool carrier unit of soil bin increased from 2.06 to 4.18 km/h, the horizontal draft increased from 65.95 to 183.82kgf.

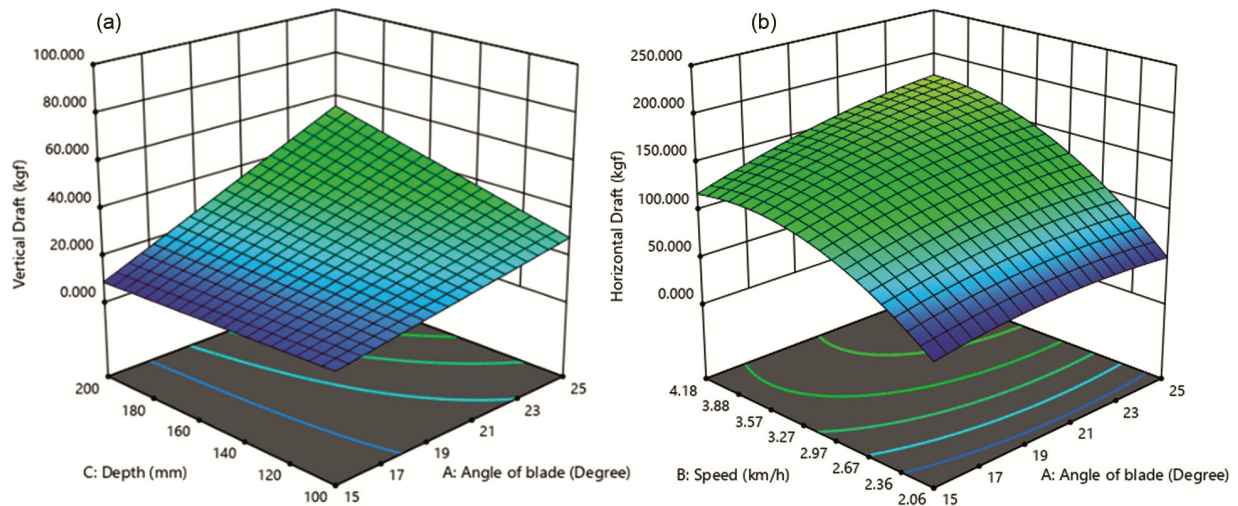


Fig. 9 — (a) Effect of angle of blade and depth on vertical draft and (b) Effect of angle of blade and speed on horizontal draft using rectangular blade.

The highest horizontal draft 183.82kgf was observed at angle of blade 25° and speed 4.18 km/h, whereas the lower vertical draft 65.95kgf was recorded for angle of blade 20° and speed 2.06 km/h, respectively.

3.7 Effect of angle of blade and depth on vertical draft of rectangular shape blade

The average values of the vertical draft at different angle of blade and depth of operation of rectangular shape blade as shown in Table 3. From Fig 9a it can be observed that as the angle of blade increased from 15 to 25° and depth of tool carrier unit of soil bin increased from 100-200 mm, the vertical draft increased from 4.057 to 89.533kgf. The highest vertical draft 89.533kgf was observed at angle of blade 25° and depth 200 mm, whereas the lower vertical draft 4.057kgf was recorded for angle of blade 15° and depth 100 mm, respectively.

3.8 Effect of angle of blade and speed on horizontal draft of rectangular shape blade

The average values of the horizontal draft at different angle of blade and speed of operation of rectangular shape blade as shown in Table 3. From Fig 9b it can be observed that as the angle of blade increased from 15 to 25° and forward speed of tool carrier unit of soil bin increased from 2.06 to 4.18 km/h, the horizontal draft increased from 38.71 to 241.67kgf. The highest horizontal draft 241.67kgf was observed at angle of blade 25° and speed 4.18 km/h, whereas the lower vertical draft 38.71kgf was recorded for angle of blade 20° and speed 2.06 km/h, respectively.

It was observed from the section 3.1 to 3.8 that the draft was increased with the increase in the rake angle

of all four types of blades in the soil bin. The increase in rake angle in all the four types of blades increased the draft of the tool because of an increase in soil resistance as the increase in rake angle increased the soil contact area. Similarly the draft was increased as the speed was increased from 2 to 4 km/h^{11,4}.

The shape of the tool penetrating and loosening the soil has a direct effect on the draft required to pull the tool for easy flow of soil and crop over the surface of the blade⁷. The minimum draft was found to be in the V-shape of blade^{6,16}. The minimum draft in V-shape was because of the smallest size of the soil shear failure plane. It was observed that the soil failed almost within the v-scoop formed by cutting edges of the share. Moreover, the soil passed over the share smoothly and there was no soil build up in front of the blade. This removes the soil surcharge pressure over the shear plane, which results in fewer drafts.

3.9 Optimization conditions

The optimization process was carried out to examine and compare the effects of all variables on dependent parameters for getting superior quality products². The two important points for optimization the data in design expert programme are graphical and statistical plots. The vertical draft and horizontal draft are found to be minimum. The goal related variables, the angle of blade, speed and depth were positioned “in range”. The optimized solution and experimental results of operating variables are listed in Table 6. The experimental data were evaluated by employing the optimum conditions to understand the obtained results from the model. Based on the experimental analysis (mean of 3 experiments)

Table 6 — Optimization variable					
Sr. No.	Angle of blade (Degree)	Speed(km/h)	Depth (mm)	Vertical draft (Kgf)	Horizontal draft (Kgf)
Optimized condition of triangular fork					
1.	20.263	2.065	100.350	2.081	51.721
Experimental results of triangular fork					
2.	20.263	2.065	100.350	2.885	49.23
Optimized condition of V shape					
1.	19.534	2.060	100.009	1.987	48.255
Experimental results of V shape					
2.	19.534	2.060	100.009	2.175	50.001
Optimized condition of convex shape					
1.	15.000	2.060	100.000	5.939	74.693
Experimental results of convex shape					
2.	15.000	2.060	100.000	6.121	75.681
Optimized condition of rectangular shape					
1.	17.398	2.082	127.119	3.313	38.710
Experimental results of rectangular shape					
2.	17.398	2.082	127.119	4.231	39.472

vertical draft and horizontal draft for four different blades were recorded. The experimental results were found to be slightly closer to the optimized solution. The optimization models were linked to the nature of optimization as well as operating conditions. Therefore, the priority of optimization would be given to those parameters that must fall into the desired range, resulting in better fitting prediction of those parameters.

4 Conclusion

The average minimum vertical draft was found to be 2.167, 2.987, 5.867 and 4.057Kgf at 15° rake angle and maximum of 26.967, 26.527, 42.473 and 89.533 Kgf at 25° rake angle for triangular fork, V-shape, convex, and rectangular shape of blades, respectively. Similarly, the mean values of the horizontal draft at different forward speed and depth of operation were found to be increased with the increase in the rake angle of all four types of blades in the soil bin. The average minimum horizontal draft was found to be 58.36, 59.317, 65.95, and 38.71Kgf at 15° rake angle and maximum of 153.517, 170.943, 183.82 and 241.67 Kgf at 25° rake angle for V-shape, convex, rectangular and triangular fork shape of blades, respectively. The overall mean draft was found to be maximum in triangular fork shape blade and minimum in V-shape blade which was selected for performance evaluation of the digger in the field.

Acknowledgements

The authors acknowledge the Agricultural Mechanization Division, CIAE, Indian Council of

Agricultural Research, Bhopal, India and Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, India for providing the testing facilities.

References

- Athmaselvi KA & Varadharaju N, *Madras Agric J*, 89(2002) 666.
- Gautam PV, Tiwari PS, Agrawal KN, Roul AK, Kumar M & Singh K, *Soil Res*, 60(2022)816.
- Gupta PD, Gupta CP & Pandey KP, *Soil Tillage Res*, 14(1989) 131.
- Harrison HP, *Trans ASAE*, 25(1982) 7.
- JhaAK & Deka BC, Meghalaya: ICAR Research Complex for NEH Region(2012) 2.
- Khura TK, Mani I & Srivastava AP, *JAERI*, 47(2010) 2.
- Klenin NI, Popor IF & Sakun VA, *Agricultural Machines*. Amerind Publishing Co Pvt Ltd. New Delhi, 1stEdn, ISBN:978-9061914488, 1985, p. 96.
- Madan MS, *ASI*, 65 (2008)193.
- Munde PA, BP Sawant, &Sawant SA, *Int J of Agri Eng*, 3(2010) 17
- Munster D, *Focaal*, 71 (2015) 100.
- Onwualu AP & Watts KC, *Soil Tillage Res*. 48 (1998) 239.
- Onwualu AP & Watts KC, *Comput Electron Agric*, 9(1993)143.
- Onwualu AP, *Tillage tool factors affecting sandy soil interaction with plane blades in a soil bin*.Ph.D Thesis, Technical University of Nova Scotia, Halifax, Canada 1991.
- Onwualu AP & Watts KC, *ASAE*, St. Joseph, MI 1989.
- Tapare VP, *Development and performance evaluation of tractor mounted turmeric digger*. M. Tech. (Agril. Engg.) Thesis, Mahatma Phule Krishi Vidyapeeth, Rahuri 2005.
- Tiwari PS, Thakur TC & Singh B, *JAERI*, 31(1994) 44.
- Zate GK, Tekale DD & Solanke KR, *MIS*, 8 (2018) 258.