



E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2017; SP1: 240-245

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Performance evaluation of mini tractor operated wavy disc type PTO powered tillage implement

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Abstract

The newly developed implement was tested in field condition to evaluate its performance. Performance analysis of the implement was carried out with Response Surface Methodology. Statistical significance of the terms was examined by analysis of variance (ANOVA) for each response using face centered central composite design. The performance of the developed implement was assessed by varying three different parameters - gang angle (20°, 25°, 30°), forward speeds (0.35, 0.77, 1.19 m/s) and depth of operation (4, 8, 12 cm) and performance was observed in terms of mean mass soil diameter, draft, fuel consumption, wheel slip and field capacity. The average values of mean mass diameter, draft, fuel consumption, wheel slip and EFC obtained during the experiments were 12.28 mm, 106.12 kgf, 11.65 l/ha, 7.27 % and 0.178 ha/h, respectively. The overall best results for the developed tillage implement were obtained at 25° gang angle with forward speed of 0.77 m/s and depth of operation as 8 cm.

Keywords: Mini tractor, disc and tillage

Introduction

Tillage mechanically manipulates the soil to provide favourable condition for crop production, which consists of breaking the compact surface of earth to a certain depth and to loosen the soil mass, so as to enable the roots of the crops to penetrate deeper and spread wider into the soil and also creates proper soil tilth for seeding and planting (Sahay, 2008) [5]. It reduces soil erosion, increases organic matter, reduces labour and fuel, improves water quality, etc.

Vertical tillage is any type of tillage that doesn't create a horizontal layer, and is performed with chisels, disk rippers, in-line rippers, parabolic rippers and combination deep tillage tools. It involves deeper tillage and tool spacing such that soil disturbance depth between the tillage shanks or tools is less (Schuler, 2007). It is a system of principles and guidelines similar to conservation agriculture that aims to improve soil health, increase water infiltration and decrease soil erosion and compaction (improve bulk density). With varying degrees of soil movement, it does not invert the soil and keep residue on the surface, where it protects the soil. It usually includes small forward-facing discs that limit soil inversion and slices the residue for faster decomposition and to get a seeders or planter into the heavy residue-laden fields.

A vertical tillage system involves understanding the soil profile, tackling compaction issues, ensuring that each pass achieves the goal of the system, respecting residue cover and providing a well prepared seedbed for the planter pass.

Material and method

To assess the performance of developed implement as well as compared the performance with the existing tillage implements, field experiments were conducted at Instructional Research Farm, College of Agricultural Engineering and Technology, AAU, Kakanpur, Godhra, Panchmahal during 2015. The experimental site is located in middle Gujarat Agro-climatic Zone of Gujarat State on N 22° 56' latitude and E 72° 53' longitude. The experimental field was having sandy loam soil.

All the parameters of the tractor-implement performance were measured and recorded in line with the recommendations of RNAM (Regional Network for Agricultural Machinery) test codes and procedures for farm machinery technical series (1983). The experiments were conducted on 20 plots of net size 1m x 30m.

Design of the experiments

A three-level, three-factor face centered central composite design was employed, which pull the axial points into the faces of the cube at +/- 1 levels. Setting alpha equal to 1 creates a Face-centered central composite design. This is desirable because it is only a three-level design, and ensures that the axial runs will not be any more extreme values than the factorial portion.

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This produces a design where each factor only has 3 levels. The second order polynomial coefficient for each term of the equation was determined through multiple regression analysis using design expert. Experimental data were fitted to the selected models and regression coefficients obtained. Statistical significance of the terms in the regression equation was examined by analysis of variance (ANOVA) for each response.

Table 1: Details of parameters under study

Independent parameters		Dependent parameters
Parameters	Levels	
Gang angle (degree)	20, 25, 30	Field capacity, wheel slip, fuel consumption, draft, soil pulverization.
Forward speed (m/s) (Gang speed, rpm)	0.35, 0.77, 1.19 (147, 191, 243)	
Depth (cm)	4, 8, 12	

Result and discussion

The soil moisture content of the field was measured in the depth range of 0-15 cm and the results revealed that the average moisture content was 15.10 %. The soil moisture revealed that field had moisture in friable range to conduct the field experiments and the data regarding bulk density of 0 - 15 cm depth soil was recorded before tillage operations. The results show that the average bulk density was 1.71 g/cc before tillage operation.

To conduct the experiments face centered central composite design was adopted with three factor three variables. Total 20 runs were carried out and data obtained during the experiments are given in table 2. To analyze the data Design Expert Software (Statease 8.0) was used to correlate the variation of responses with independent variables. Performance analysis of the implement was carried out with Response Surface Methodology which reduces number of experiments. Statistical significance of the terms was examined by analysis of variance (ANOVA) for each response using face centered central composite design. The significance of all terms in the polynomial was judged statistically by computing the F-value at probability (P) of 0.1 to 0.01. A complete second order quadratic model employed to fit the data and adequacy of the model was tested.

Optimization of process parameters was done by partially differentiating the model with respect to each parameter, equating to zero and simultaneously solving the resulting function. The regression coefficients were then used to make statistical calculation to generate three-dimensional plots for the regression model.

Optimization of process parameters was done by partially differentiating the model with respect to each parameter, equating to zero and simultaneously solving the resulting function. The regression coefficients were then used to make statistical calculation to generate three-dimensional plots for the regression model.

Effect of different parameters on Mean mass diameter

Mean mass diameter of the vertical tillage implement ranged from 10.80 mm to 14.51 mm with an average value of 12.28 mm. The maximum MMD created by developed implement at coded point (30°, 0.35m/s, 12cm) was about 1.34 times more than the minimum MMD at coded point(20°, 1.19m/s, 4cm) (table 2).

Mean mass diameter model in terms of un-coded factors

$$\text{MMD} = +11.90 + 0.25 X_1 - 0.67 X_2 + 0.83 X_3 + 0.11 X_1 X_2 + 0.039 X_1 X_3 - 0.039 X_2 X_3 + 0.42 X_1^2 + 0.25 X_2^2 + 0.064 X_3^2 \dots \quad (1)$$

Mean mass diameter model in terms of coded factors

$$\text{MMD} = +23.03 - 0.84 X_1 - 4.89 X_2 + 0.11 X_3 + 0.05 X_1 X_2 + 1.93E-003 X_1 X_3 - 0.02 X_2 X_3 + 0.01 X_1^2 + 1.43 X_2^2 + 3.97E-003 X_3^2 \quad (2)$$

Table 2: Analyzed data for developed vertical tillage implement using Face Centered Central Composite Design

Run	Independent variables			Dependent variables				
	Factor-1 X ₁ Gang angle (degree)	Factor-2 X ₂ Forward speed (m/s)	Factor-3 X ₃ Depth (cm)	Response-1 Y ₁ Draft (kgf)	Response-2 Y ₂ Fuel consumption (l/ha)	Response-3 Y ₃ Wheel slip (%)	Response-4 Y ₄ EFC (ha/h)	Response-5 Y ₅ MMD (mm)
1	30	1.19	4	112.68	10.00	6.99	0.26	11.50
2	30	0.77	8	112.08	14.37	7.42	0.17	12.52
3	25	0.77	8	102.60	10.00	7.15	0.18	12.04
4	25	0.77	8	105.36	10.31	7.03	0.18	12.07
5	25	0.77	8	102.76	10.00	6.92	0.17	11.98
6	25	0.77	4	95.76	12.50	7.10	0.17	11.09
7	25	0.77	12	112.00	10.00	6.86	0.17	12.49
8	20	1.19	12	116.68	8.12	6.72	0.26	12.49
9	30	1.19	12	118.16	10.00	6.74	0.26	13.08
10	25	1.19	8	116.56	8.75	7.14	0.26	11.49
11	20	0.35	4	91.60	12.50	7.66	0.09	12.50
12	20	0.35	12	100.76	18.75	7.77	0.08	14.08
13	25	0.77	8	104.16	10.25	6.91	0.18	12.03
14	30	0.35	4	107.28	12.50	7.67	0.08	12.51
15	25	0.77	8	102.72	10.00	6.90	0.18	12.00
16	25	0.77	8	101.12	10.50	6.99	0.18	12.01
17	25	0.35	8	94.24	18.75	7.13	0.08	12.47
18	30	0.35	12	114.60	18.75	7.15	0.09	14.51
19	20	1.19	4	110.56	7.50	7.19	0.26	10.80
20	20	0.77	8	100.64	9.37	9.92	0.18	11.77

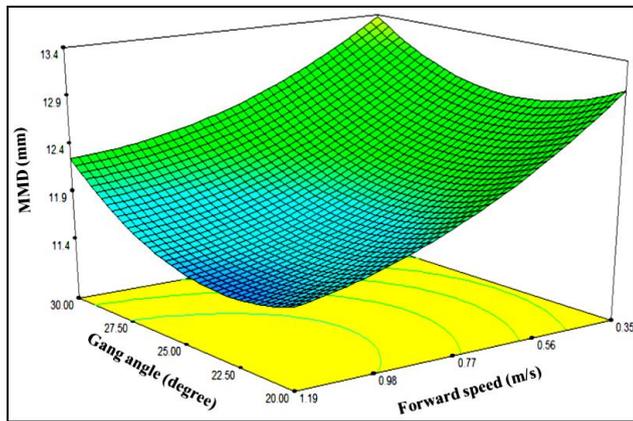


Fig 1: Variation of MMD with respect to gang angle and forward speed.

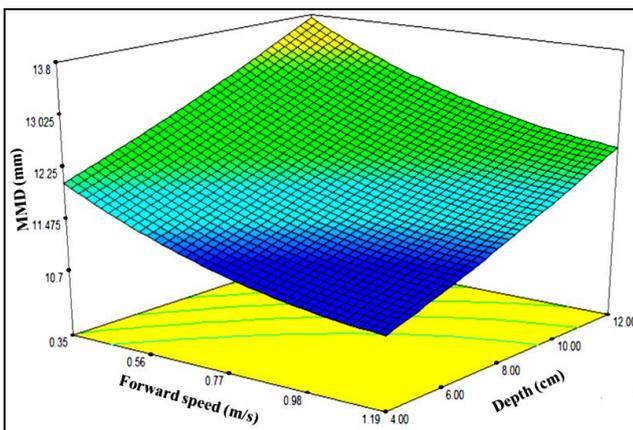


Fig 2: Variation of MMD with respect to forward speed and depth.

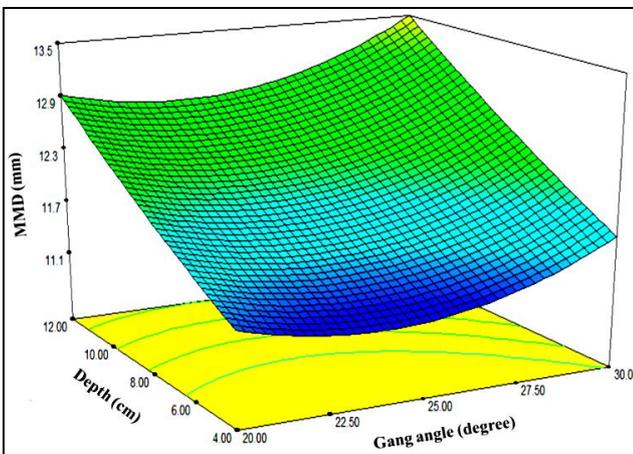


Fig 3: Variation of MMD with respect to depth and gang angle

Analysis of variance of Eq. (1) shows that F-values for linear terms of gang angle, forward speed and depth are 12.57, 92.03 and 139.11 at p value of 0.0053, < 0.0001 and < 0.0001, respectively, showing that the terms are significant terms (P<0.10) (ANOVA). F-values for square terms of gang angle (X_1^2), forward speed (X_2^2) and depth (X_3^2) are 9.85, 3.62, 0.23 at p values of 0.0105, 0.0864, 0.6436, respectively, showing that X_1^2 and X_2^2 terms are significant. F-values for interaction terms gang angle, forward speed and depth with MMD (X_1X_2 , X_2X_3 and X_1X_3) are 1.85, 0.25 and 0.25 at p values of 0.2041, 10.631 and 0.631 respectively, indicating that all the terms are

not significant.

Effect of different parameters on draft

Draft of the vertical tillage implement ranged from 91.60 kgf to 118.16 kgf with an average value of 106.12 kgf. The maximum draft of developed implement at coded point (30°, 1.19m/s, 12cm) was about 1.29 times more than the minimum draft at coded point (20°, 0.35m/s, 4cm) (table 2).

Draft model in terms of un-coded factors

$$\text{Draft} = +103.17 + 4.46 X_1 + 6.62 X_2 + 4.43 X_3 - 3.24 X_1 X_2 - 0.31 X_1 X_3 - 0.61 X_2 X_3 + 3.11 X_1^2 + 2.15 X_2^2 + 0.63 X_3^2 \dots (3)$$

Draft model in terms of coded factors

$$\text{Draft} = +112.32 - 4.01 X_1 + 38.46 X_2 + 1.14 X_3 - 1.54 X_1 X_2 - 0.01 X_1 X_3 - 0.36 X_2 X_3 + 0.12 X_1^2 + 12.18 X_2^2 + 0.03 X_3^2 \dots (4)$$

Analysis of variance of Eq. (3) show that F-values for linear terms of gang angle, forward speed and depth are 19.75, 43.55 and 19.54 at p value of 0.0012, < 0.0001 and 0.0013, respectively, showing that the X_1 , X_2 and X_3 are the significant terms (P<0.10) (ANOVA). F-values for square terms of gang angle (X_1^2) and forward speed (X_2^2) and depth (X_3^2) are 2.64, 1.26 and 0.11 at p values of 0.1350, 0.2872 and 0.7489, respectively (P<0.10), showing that all the terms are not significant. F-values for interaction terms gang angle, forward speed and depth with draft (X_1X_2 , X_2X_3 and X_1X_3) are 8.36, 0.3 and 0.08 at p values of 0.0161, 0.5982 and 0.7877, respectively, indicating that X_1X_2 term is significant (P<0.05).

Effect of different parameters on fuel consumption

Fuel consumption of the vertical tillage implement ranged from 7.50 l/ha to 18.75 l/ha with an average value of 11.65 l/ha. The maximum fuel consumption of developed implement at coded point (30°, 0.35m/s, 12cm) was about 2.5 times more than the minimum fuel consumption at coded point (20°, 1.19m/s, 4cm) (table 2).

Fuel consumption model in terms of un-coded factors

$$\text{Fuel Consumption} = +10.80 + 0.94 X_1 - 3.69 X_2 + 1.06 X_3 + 0.55 X_1 - 0.078 X_1 X_3 - 1.48 X_2 X_3 + 0.15 X_1^2 + 2.03 X_2^2 - 0.47 X_3^2 \dots (5)$$

Fuel consumption model in terms of un-coded factors

$$\text{Fuel Consumption} = +18.20 - 0.28 X_1 - 25.9 X_2 + 1.51 X_3 + 0.26 X_1 X_2 - 3.90E-003 X_1 X_3 - 0.88 X_2 X_3 + 6.02E-003 X_1^2 + 11.48 X_2^2 - 0.02 X_3^2 \dots (6)$$

Analysis of variance of Eq. (5) shows that F-values for linear terms of gang angle, forward speed and depth are 2.75, 42.56 and 3.53 at p value of 0.1282, < 0.0001 and 0.0896, respectively, showing that the X_2 and X_3 are the significant terms (P<0.10) (ANOVA). F-values for square terms of gang angle (X_1^2), forward speed (X_2^2) and depth (X_3^2) are 0.02, 3.53 and 0.19 at p values of 0.8917, 0.0896 and 0.6692, respectively (P<0.10), showing that X_2^2 term is significant. F-values for interaction terms gang angle, forward speed and depth with fuel consumption (X_1X_2 , X_2X_3 and X_1X_3) are 0.75, 5.52 and 0.02 at p values of 0.4071, 0.0407 and 0.9041, respectively, indicating that all the terms are significant (P<0.10).

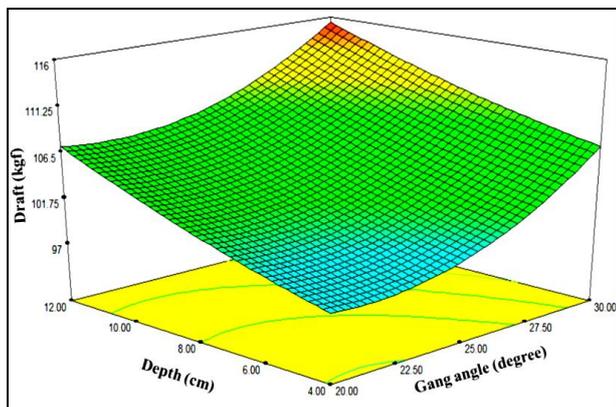


Fig 4: Variation of draft with respect to depth and gang angle.

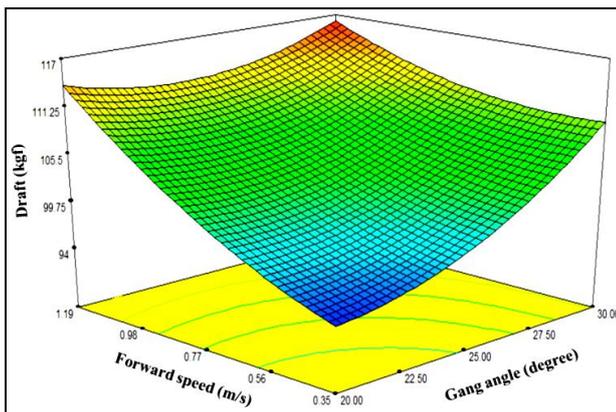


Fig 5: Variation of draft with respect to forward speed and gang angle.

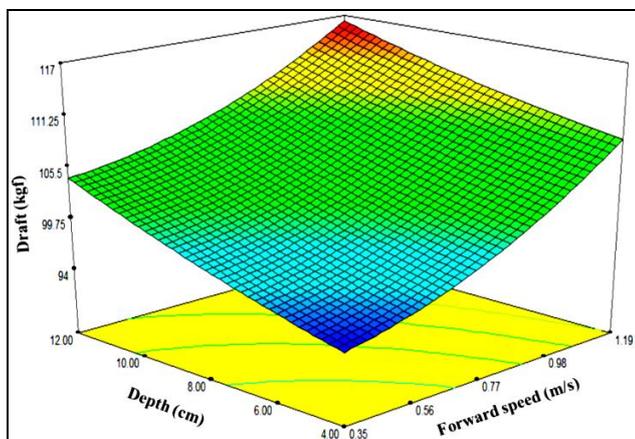


Fig 6: Variation of draft with respect to depth and forward speed

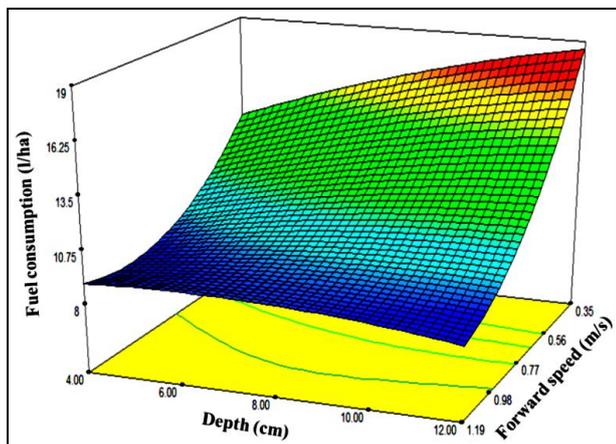


Fig 7: Variation of fuel consumption with respect to depth and forward speed.

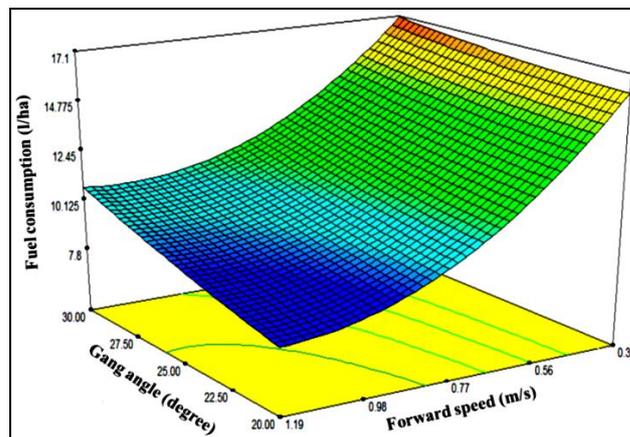


Fig 8: Variation of fuel consumption with respect to gang angle and forward speed.

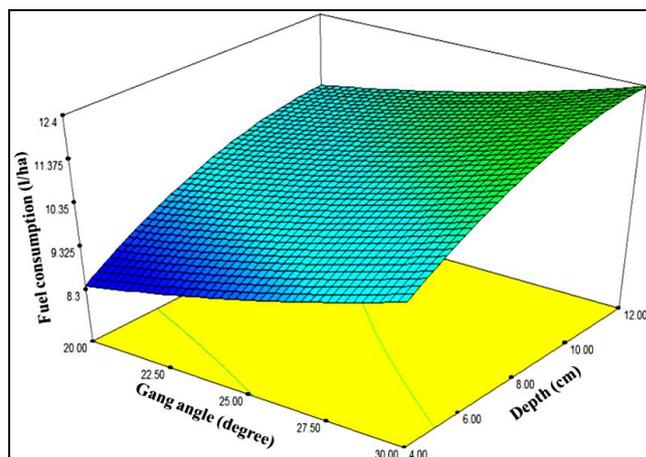


Fig 9: Variation of fuel consumption with respect to gang angle and depth.

Effect of different parameters on wheel slip

Wheel slip of the vertical tillage implement ranged from 6.72 % to 9.93 % with an average value of 7.27 %. The maximum wheel slip of developed implement at coded point (20°, 0.77m/s, 8cm) was about 1.47 times more than the minimum wheel slip at coded point(20°, 1.19m/s, 12cm) (table 2).

Wheel slip model in terms of un-coded factors

$$\text{Wheel slip} = +7.21 - 0.33 X_1 - 0.26X_2 - 0.14 X_3 + 0.05 X_1X_2 - 0.05 X_1X_3 - 0.03 X_2X_3 + 1.11 X_1^2 - 0.42 X_2^2 - 0.58 X_3^2 \dots (7)$$

Wheel slip model in terms of coded factors

$$\text{Wheel slip} = +33.49 - 0.28 X_1 + 2.62 X_2 + 0.62 X_3 + 0.02 X_1 X_2 - 2.56E-003 X_1 X_3 - 0.02 X_2 X_3 + 0.04X_1^2 - 2.40 X_2^2 - 0.03 X_3^2 \dots (8)$$

Analysis of variance of Eq. (7) show that F-values for linear terms of gang angle, forward speed and depth are 3.07, 1.92 and 0.53 at p value of 0.1103, 0.1963 and 0.4824, respectively, showing that all the terms are not significant(ANOVA).F-values for square terms of gang angle (X_1^2), forward speed (X_2^2) and depth (X_3^2) are 9.63, 1.40 and 2.61 at p values of 0.0112, 0.2641 and 0.1372, respectively ($P < 0.10$), showing that X_1^2 term is significant. F-values for interaction terms gang angle, forward speed and depth with wheel slip (X_1X_2 , X_2X_3 and X_1X_3) are 0.07, 0.03 and 0.06 at p values of 0.8031, 0.8572 and 0.8121, respectively, indicating that all the terms are not significant.

Effect of different parameters on effective field capacity

Effective field capacity of the vertical tillage implement

ranged from 0.089 ha/h to 0.268 ha/h with an average value of 0.178 ha/h. The maximum EFC of developed implement at coded point (30°, 0.35m/s, 12cm) was about 2.5 times more than the minimum EFC at coded point (20°, 1.19m/s, 4cm) (table 2).

EFC model in terms of un-coded factors

$$EFC = +0.18 - 1E - 003X_1 + 0.08 X_2 + 2.5E-003X_1X_3 + 1.81E-003X_1^2 - 3.18E-003X_2^2 - 3.18E - 003 X_3^2 \dots(9)$$

EFC model in terms of coded factors

$$EFC = +0.06 - 4.83E-003 X_1 + 0.23 X_2 + 5.68E-005 X_3 + 1.25E-004 X_1 X_3 + 7.27E-005 X_1^2 - 0.01 X_2^2 - 1.98E-004 X_3^2 \dots(10)$$

Analysis of variance of Eq. (9) show that F-values for linear terms of gang angle, forward speed and depth are 0.37, 2858.52 and 0 at p value of 0.557, < 0.0001 and 1 respectively, showing that the model X2 is significant term (ANOVA). F-values for square terms of gang angle (X₁²), forward speed (X₂²) and depth (X₃²) are 0.34, 1.03, 1.03 at p values of 0.5752, 0.3346, 0.3346 respectively, showing that all the terms are not significant. F-values for interaction terms gang angle, forward speed and depth with EFC (X₁X₂, X₂X₃ and X₁X₃) are 0, 0 and 1.85 at p values of 1, 1 and 0.2041 respectively, indicating that all the terms are not significant.

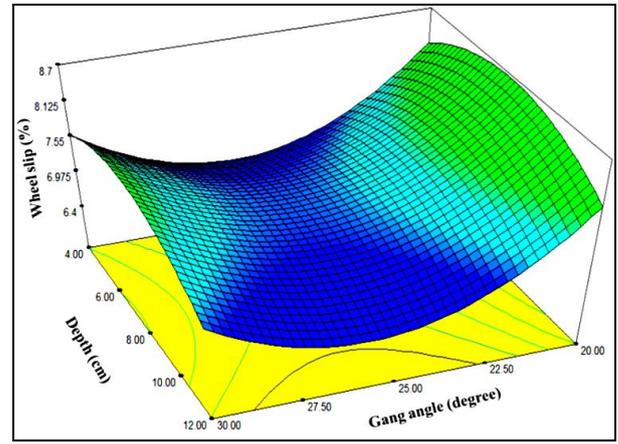


Fig 12: Variation of wheel slip with respect to depth and gang angle.

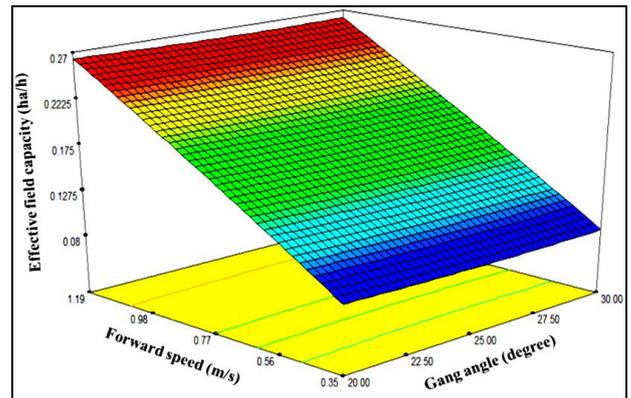


Fig 13: Variation of EFC with respect to forward speed and gang angle.

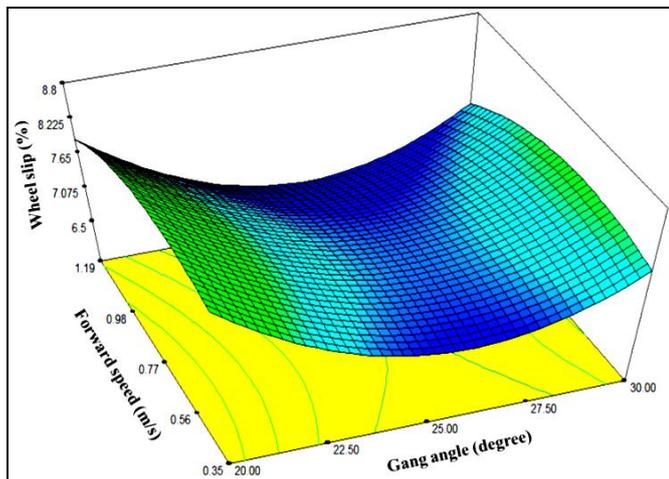


Fig 10: Variation of wheel slip with respect to forward speed and gang angle.

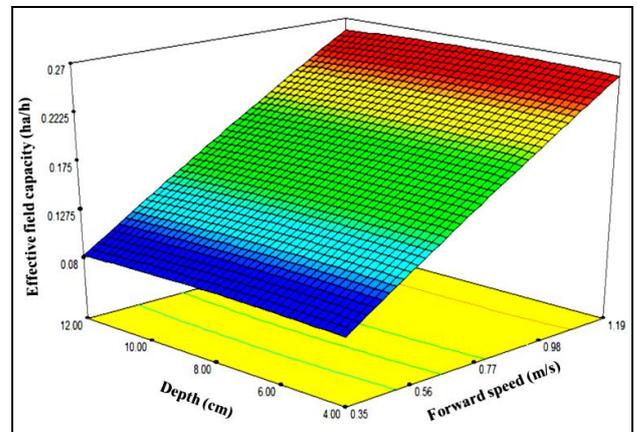


Fig 14: Variation of EFC with respect to forward speed and depth

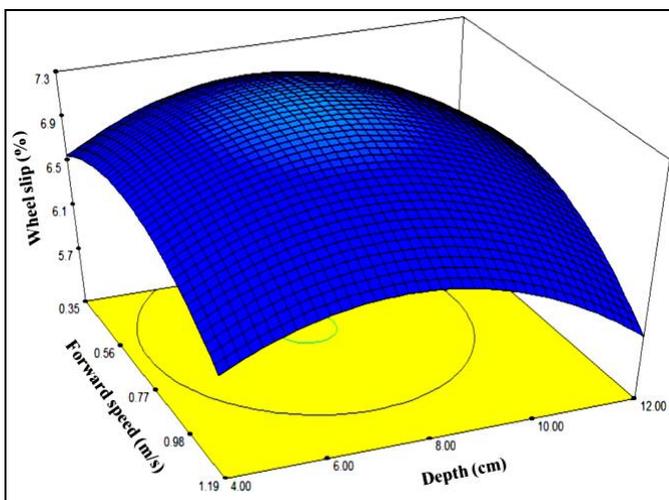


Fig 11: Variation of wheel slip with respect to forward speed and depth

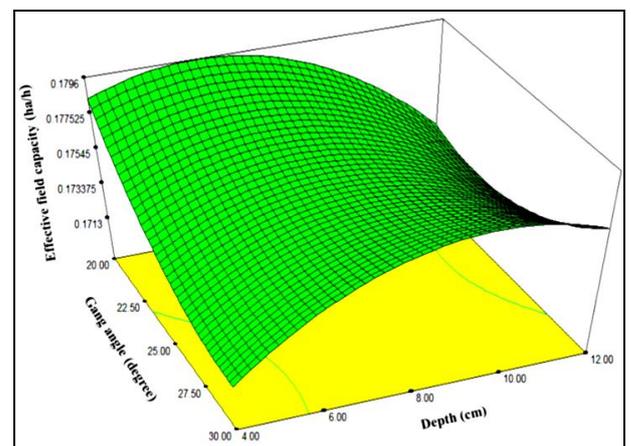


Fig 15: Variation of EFC with respect to gang angle and depth.

Optimization of Developed Vertical Tillage Implement Performance

The data obtained from the 20 runs of experiments were analyzed using Face Centered Central Composite Design. The optimization with different independent (Factors) and dependent parameters (responses) was carried out using manual regression quadratic model with the help of Design Expert 8.0 software. The analyzed data of developed

implement in graphical form are shown Fig. 1 to 15 and the model incoded and un-coded factors are given in Eq. 1 to 10. The best results among different gang angles under study, gang wise optimum values were calculated and given in table 3. It is clear from the data that at 25° gang angle will give superior desirability as compared to 20° and 30° gang angle at forward speed of 0.77 and depth of 8 cm.

Table 3: Overall best results at optimized value for the developed implement.

Gang angle (degree)	Forward speed (m/s)	Depth (cm)	Fuel consumption (l/ha)	Draft (kgf)	Wheel slip (%)	EFC (ha/h)	MMD (mm)	Desirability
20	0.77	8.28	10.09	102.16	8.65	0.18	12.13	0.71
25	0.77	8	9.49	106.84	6.99	0.18	11.64	0.78
30	0.77	4	10.43	107.24	7.61	0.17	11.77	0.61

Conclusion

Mean mass diameter of the vertical tillage implement ranged from 10.80 mm to 14.51 mm with an average value of 12.28 mm. It increased with depth of operation but decreased with forward speed and at 25° gang angle it was minimum at lower depth. The mean mass soil diameter (MMD) created by the developed implement significantly influenced by gang angle, forward speed and depth of operation. But, their interactions were not significant.

Draft of the vertical tillage implement ranged from 91.60 kgf to 118.16 kgf with an average value of 106.12 kgf. It increased with increase in gang angle, forward speed and depth of operation. Also, effect of these parameters on draft was significant.

Fuel consumption increased with the increase in gang angle, forward speed and depth of operation with a maximum and minimum value of 18.75 l/ha and 7.50 l/ha, respectively. It was significantly influenced by forward speed and depth of operation.

Wheel slip of the vertical tillage implement ranged from 6.72 % to 9.93 % with an average value of 7.27 %. The effect of different independent parameters under study and their interactions on wheel slip was not significant.

Effective field capacity of the vertical tillage implement ranged from 0.089 ha/h to 0.268 ha/h with an average value of 0.178 ha/h. Only forward speed significantly influenced the EFC.

The overall best results for the developed tillage implement were obtained at 25° gang angle with forward speed of 0.77 m/s and depth of operation as 8cm.

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