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EVALUATION OF THE IMPACT OF OPERATIONAL ANGLES AND DEPTH OF CUT ON THE PERFORMANCE OF A DISC HARROW ON SANDY-LOAM SOIL IN UMUAHIA

Okeke C.G.*[1], Egwuagu O.M [1], Dim E. C.[2]
1 Department of Mechatronics Engineering, Enugu State University of Science and Technology
2 Department of Mechanical and Production Engineering, Enugu State University of Science and Technology.
Author for correspondence: Okeke C.G; **E-mail**: chineze.okeke@esut.edu.ng

Abstract - Operation angles and depth of cut of a disc harrow on sandy-loam soil in Umuahia were studied. This is because different agroecological soil condition requires detailed statistical data on how tillage equipment performs on various soil types. Such data helps a farmer to select the right implement to save cost, conserve energy, and increase production. The research aimed to evaluate the performance of the disc-harrow on loam-sandy soil in Umuahia, to guide users in knowing Its power, efficiency, and energy requirement of the harrow so they can choose the most suitable harrow for optimal and efficient production based on soil type. A 65 horsepower Massey Ferguson 375 tractor, known for its reliability and efficiency in field operation, and an offset disc harrow of John Deere DH12 model were used for the study. This harrow weighed 1,200kg, with a disc diameter of 610mm and disc spacing of 230mm, suitable for effective soil preparation in sandy loamy soils. Results showed that the harrow recorded the highest field efficiency of 90.42% when it was operated at 20^0 angles and 21cm depth of cut. At this angle and depth, the harrow had an effective field capacity and theoretical field capacity of 1.139ha/hr and 0.012597ha/hr respectively. The least field efficiency (F.E) of 86.48% was observed at 20^0 angles and 14cm vertical depth. At this angle and depth, the corresponding theoretical field capacity was 0.011347ha/hr. The study concluded that the optimal performance of the disc harrow on sandy-loam soil in Umuahia was achieved at a 20° angle and 21 cm depth of cut, with the highest field efficiency of 90.42%. These findings provide valuable insights for farmers in selecting appropriate tillage settings to enhance efficiency.
Keywords: angles, depth, harrow, performance, sandy-loam soil

1. Introduction

Farmers's soil preparation is an essential step for cultivation and growing crops. This process changes how the soil is put together lets more air in, and helps water soak in and stay there. Lal (2015) says farmers do this to get the soil ready for seeds, kill weeds, and mix in plant matter and fertilizers. Breaking up packed soil and making it loose helps roots grow better and makes crops healthier overall. Getting the soil just right plays a big role in growing as much as possible. Soil that's been worked well gives seeds a good place to sprout and roots room to grow, which plants need to thrive. Alam et al., (2014) point out that working the soil the right way can lead to much bigger harvests. It does this by making the soil's physical traits better, like porosity and compaction. This allows roots to push through more and take in more nutrients. Also, prepping the soil well helps control how much water is in it so crops have enough water while they grow. Moreover, good plowing plays a key role in fighting weeds. It messes up weed growth and buries their seeds cutting down on the fight for resources between crops and weeds. This matters a lot when crops are young and cannot handle weed competition well (Carter 1993). Also, mixing organic stuff into the soil while plowing makes the soil richer and better structured. This gives plants the food they need to grow and helps good microbes in the soil do their job (Six et al. 2004). Disc harrows are key tools in today's farming, used a lot for main and follow-up plowing. They are good at breaking up dirt clumps mixing in leftover crops, and smoothing out the soil surface. These steps are crucial to create the best soil for planting seeds (Grisso et al. 2013). Farmers can use disc harrows in many soil types and conditions making them must-haves for farm work that aims to improve soil structure and grow more crops. A disc harrow consists of curved metal discs attached to a shared shaft or axle. These discs form two or more gangs, each set at an angle to the travel direction. The discs' concave shape helps them dig into the soil and slice through crop leftovers, while their angled setup aids in soil turning and even mixing of organic matter (Srivastava et al., 2006). When pulled across a field, the spinning discs cut into the soil, lift it, and push it sideways. This breaks up packed layers and creates finer soil texture ready for planting. The main parts of a disc harrow include the frame, which holds the disc gangs and keeps the tool steady during use, and the disc gangs, which do the main work. Bearings and axles let the discs spin, while scrapers keep soil and debris from building up on the discs, which helps the tool work well. Also, farmers can change the disc harrow's weight and disc angles to get the right depth and strength of tillage. This makes it a flexible tool for many farming needs. There is a pressing need for research to identify best practices for disc harrow operation. Such research can provide valuable insights into the optimal settings for different soil types and conditions, helping farmers improve their tillage efficiency and crop yields. Studies focusing on the interaction between operational parameters and soil characteristics can lead to the development of guidelines and recommendations tailored to specific farming environments (Kouwenhoven et al., 2002). Additionally, advancements in technology, such as precision agriculture tools, can be integrated into disc harrow operations to enhance accuracy and reduce resource wastage. Abia State, located in southeastern Nigeria, has a diverse agricultural landscape with significant areas of sandy loamy soil (Obalum et al., 2011). Agriculture is a major economic activity in the state, and optimizing soil tillage practices can enhance crop yields and support food security (Okoroafor and Nwaobiala, 2014). By evaluating the effects of operational angles, depth of cut, and moisture content on sandy-loamy soil, this study aims to provide valuable insights that can guide farmers in Abia State toward more efficient and sustainable tillage practices. The basic aim of this research is to evaluate the effects of operational angles, penetration/vertical level of cut, and amount of water in the soil on the disc harrow’s output in Abia State.

2. Materials and Methods

2.1 Study area

This experimental site is situated in the southeastern part of the Country, with geographical coordinates roughly between latitudes 5°25'N and 5°17'N and longitudes 7°00'E and 7°10'E. Abia State has a tropical rainforest climate, marked by heavy rainfall, high humidity, and consistently warm temperatures annually. Yearly rainfall varies from 2000 mm to 2500 mm. An average temperature hovers around 27°C, showing little fluctuation. In Umudike, Ikwuano, Abia State, the dominant soil type is sandy loam, recognized for its excellent drainage, moderate fertility, and ease of tillage. Sandy loamy soils are well-suited for a range of crops due to their balanced texture, which facilitates proper root penetration and air circulation (Nigeria Media, 2023; Jaskulska et al., 2020). The experimental site is located at the Demonstration site of Agricultural Engineering in Umudike. This area features relatively flat terrain with a history of agricultural use, making it ideal for tillage experiments. The region is representative of the typical sandy-loamy soils found locally, providing a relevant backdrop for examining the effects of disc harrow operational parameters.

2.2 Experimental Design

The study explores how operational angles, depth of cut, and water content influence the efficiency of disc harrowing in sandy-loamy soils. A factorial design was used for the experiment to assess the interactions among these factors. The experimental area was divided into plots measuring 10 meters by 10 meters. Each plot received different treatments based on various combinations of operational angles, depth of cut, and soil moisture levels. To reduce the impact of soil variability, an RCBD (Randomized Complete Block Design) was implemented, ensuring that conducts were arbitrarily allocated to the map-out area. Each treatment (conduct) was replicated three times to improve the reliability of the findings.

2.3 Machine and implement used for the study

The study involved a 65-horsepower Massey Ferguson 375 tractor, recognized for its reliability and efficiency in fieldwork. This tractor is powered by a 4-cylinder diesel engine, providing ample strength for demanding agricultural tasks, such as tillage. It comes with a manual transmission that offers various speed options, enabling precise control during operations. The hydraulic system of the tractor facilitates the smooth attachment and functioning of implements, including tillage tools. For the tillage tasks, an offset disc harrow, specifically the John Deere DH12 model, was utilized. This harrow weighs 1,200 kg, has a disc diameter of 610 mm, and also disc spacing of 230 mm, making it ideal for effective soil preparation in sandy loamy soils. The operational angles of the harrow were adjusted using its built-in angle adjustment mechanism, and to ensure accuracy, a protractor was employed to measure and confirm the chosen angles.

The depth settings for the experiment were 5 cm, 10 cm, and 15 cm. The depth was modified using the hydraulic system of the disc harrow. To verify the depth, measurements of the penetration depth were taken with a ruler (depth gauge) before and after each tillage operation.

2.4 Measurement of Soil water level

The moisture content of soil samples collected from the trial site was determined using the oven-dry method, as described by Okeke et al. (2020). In the lab, the mass of the wet soil specimens (initial samples) and Desiccated soil samples (dry soil) were measured. Soil water was calculated using Equation (1)

$$M\_C = [(W\_S - D\_S) / D\_S] \times 100\% \quad (1)$$

Where: M_C = Amount of water in the soil (%),

W_S = initial weight of the wet soil sample, in kg, and

D_S = the dry soil weight, in kg.

2.5 Evaluation of Theoretical Field Capacity (TFC)

The TFC was calculated using Equation 2, adopted by Oduma et al. (2023), from Kepner et al. (1982) and later

$$C_t = \frac{S \times W}{10} \quad (2)$$

Where,

C_t = TFC, ha/h

S = Tractor speed, km/h

W = width of Implement, m

2.6 Evaluation of EFC (Effective Field Capacity)

The EFC was measured by utilizing Equation (3)

$$C_e = \frac{A}{T_t} \quad (3)$$

Where:

C_e= EFC, ha/h

A = Actual covered area, ha

T_t= Total time working, h

2.7 Determination of FE (Field Effectiveness/ Field Efficiency)

The FE was figured out by a formula from Oduma et al. (2018).

$$\varepsilon_f = \frac{100T_p}{T_t} \quad (4)$$

Where:

ε_f = Field efficiency, %:

T_p = effective time, h:

T_t = Total hours working, h.

$T_t = T_p + T_i$ and T_i is the delay time or idle hour (h)

2.8 Analysis and Data

Data collected was analyzed using Design Expert version 11.0, which became instrumental in optimizing the practical factors examined in the study of how operational angles and cutting depth influence the output of a disc harrow on sandy-loam soil in Umuahia. This software also facilitated the creation of empirical regression models to estimate the field efficiency, theoretical field capacity, and effective field capability. Multiple models, including quadratic, linear, cubic, and two-factor interaction (2F1), were applied to assess the field effectiveness, consumption rate of fuel, draft force, and draw-bar power. These models were subsequently suitable for the research figures collected.

Further analysis of the data was run with Response Surface Methodology (RSM), which assisted in fitting the quadratic polynomial expression produced by the Design Expert application, as illustrated in Equation (5) (Chih et al., 2012)

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n} \beta_{ii} X_i^2 + \sum_{i=1}^{n} \sum_{j=i+1}^{n} \beta_{ij} X_i X_j \quad (5)$$

Where:

- Y = Response variable
- β_0 = Constant term
- $\sum_{i=1}^{n} \beta_i X_i$ = Linear terms
- $\sum_{i=1}^{n} \beta_{ii} X_i^2$ = Quadratic terms
- $\sum_{i=1}^{n} \sum_{j=i+1}^{n} \beta_{ij} X_i X_j$ = Interaction terms
- Xi, Xj = Predictor variables

Moreover, diversified regression analysis was employed to align the coefficients of the polynomial model, linking the response variables with the predictor variables. The authenticity of the model's relevance, along with the impact of tillage parameters (tillage angles and cutting depth) on the responses (fuel consumption rate, field efficiency, drawbar power, and draft force), were assessed through ANOVA (analysis of variance) with crucial level set at $p < 0.05$, utilizing Minitab 17.0.3.0.

Results and Discussion

3.1 Observed site performances of disc Harrow

The observed performance of the disc harrow is detailed in Table 1. The data shows that the harrow achieved its highest field efficiency of 90.42% when operated at a tilt angle of 20 degrees and a cutting/penetration depth of 21 cm; by this setting, the TFE and EFC were recorded at 0.012597 ha/hr and 1.139 ha/hr, respectively, with a fuel consumption rate of 0.33 l/hr. Conversely, the minimum field efficiency of 86.48% was noted at the same angle of 20 degrees but with a cutting/penetration depth of 14 cm. Here, both the theoretical and effective field capacities were 0.012601 ha/hr.

Table 1. Observed/Actual values of Field performances of disc harrow

Runs	Tilt Angle	Depth of cut	Moisture content	Theoretical field capacity	field capacity	Field Efficiency
1	20	14	20.5	0.012612	1.123000	89.04
2	20	21	15.5	0.012598	1.124000	89.23
3	20	21	15.5	0.012590	1.109000	88.02
4	20	28	10.5	0.012600	1.122000	89.02
5	20	21	15.5	0.012950	1.12200	89.08
6	20	21	15.5	0.012600	1.121000	88.95
7	20	21	15.5	0.012600	1.109000	88.01
8	20	21	15.5	0.012600	1.112000	88.24
9	15	21	20.5	0.012610	1.115000	88.45
10	20	21	15.5	0.012601	1.127000	89.44
11	20	21	15.5	0.012600	1.129600	89.65
12	20	21	15.5	0.012597	1.139000	90.42
13	20	14	10.5	0.012601	1.126010	86.48
14	15	21	10.5	0.012625	1.089800	87.25
15	25	28	15.5	0.012624	1.089700	88.01
16	25	14	15.5	0.0126230	1.090100	89.50

3.2 Statistical Analysis

3.2.1 Theoretical Field Capacity (TFC)

Table 2 presents the ANOVA results for the quadratic model analyzing theoretical field capacity during disc harrowing. The model was found to be statistically insignificant ($P > 0.05$), with an F-statistic of 3.06, indicating a 9.31% probability that this value is due to random variation.

P-values below 0.05 suggest statistically significant model terms, while values exceeding 0.10 indicate non-significance. In this study, A^2 was identified as a significant term, whereas other terms lacked statistical relevance. To improve model accuracy, non-significant terms (except those required to maintain model hierarchy) may need to be refined or removed. The model fit test showed a Lack of Fit F-statistic of 5.08, with a probability of 10.74%, meaning the lack of fit is not statistically significant when compared to pure error. This is a desirable outcome, as it suggests the model aligns well with the observed data.

Table 2 ANOVA for Quadratic model of theoretical field capacity

Source	Total of Squares	df	Average Square	F-value	p-value	
Model	2.097E-09	9	2.330E-10	3.06	0.0931	not significant
A-Tilt Angle	1.051E-10	1	1.051E-10	1.38	0.2842	
B-Dept of Cut	1.445E-10	1	1.445E-10	1.90	0.2172	
C-MC	2.112E-11	1	2.112E-11	0.2778	0.6171	
AB	2.500E-13	1	2.500E-13	0.0033	0.9561	
AC	1.440E-10	1	1.440E-10	1.89	0.2179	
BC	3.025E-11	1	3.025E-11	0.3978	0.5515	
A^2	1.332E-09	1	1.332E-09	17.52	0.0058	
B^2	2.890E-10	1	2.890E-10	3.80	0.0991	
C^2	3.025E-11	1	3.025E-11	0.3978	0.5515	
Residual	4.563E-10	6	7.604E-11			
Lack of Fit	3.813E-10	3	1.271E-10	5.08	0.1074	not significant
Pure Error	7.500E-11	3	2.500E-11			
Cor Total	2.553E-09	15				

Table 3 presents the Fit Statistics for the theoretical field capacity of the harrow. The negative forecasted R^2 indicates that the whole average could potentially be a greater reliable predictor for the response than the current model. Some certain cases, a higher-order model could yield improved prognostication. Adequacy Precision evaluates the SNR (signal-to-noise ratio), with a preference for ratios above 4. With a ratio of 5.059, the model demonstrates an adequate signal. This model is appropriate for investigating the design space.

The final regression equation for theoretical field capacity (TFC) in terms of actual factors is expressed as equation (6)

This equation represents the relationship between the theoretical field capacity (TFC) and the three key operational parameters—tilt angle, depth of cut, and soil moisture content. The negative coefficients of T, D, and M suggest that increasing these parameters individually may reduce TFC. However, the positive interaction terms (TD, TM, DM) indicate that specific combinations of these variables could enhance field capacity under certain conditions. This model helps in understanding how adjustments to tillage settings affect efficiency and can be used to optimize disc harrow performance on sandy-loam soils.

Table 3 Fit Statistics for Theoretical Field Capacity

Std. Dev.	8.720E-06	**R^2**	0.8213
Mean	0.0126	**Modified R^2**	0.5532
C.V. %	0.0691	**Forecasted R^2**	-1.4416
		Adeq Precision	5.0588

Final Equation in Terms of Actual Factors

TFC = 0.013118 – 0.000034T – 9.25357E-06D -9.535E-06M +7.17286E-TD + 2.4E-07TM + 7.8574E-08DM + 7.3E-07T^2 + 1.73469E-07D^2 + 1.1E-07M^2 (6)

Where T = Tilt angle, degrees; D = Depth of cut, cm; M = moisture content, %

E = exponent

Table 4 presents the Fit Summary for the theoretical field capacity during the harrow operation. The results in this table suggest that a quadrant model is endorsed for furcating/predicting the theoretical field capacity of the harrow.

Table 4 Fit rundown of Theoretical Field Capacity

Source	Sequential p-statistic	Lack of Fit P-statistic	modified R^2	Predicted R^2	
Linear	0.7058	0.0431	-0.1174	-0.5293	
2FI	0.8605	0.0281	-0.3760	-1.8002	
Quadratic	**0.0203**	**0.1074**	**0.5532**	**-1.4416**	**Suggested**
Cubic	0.1074		0.8531		Aliased

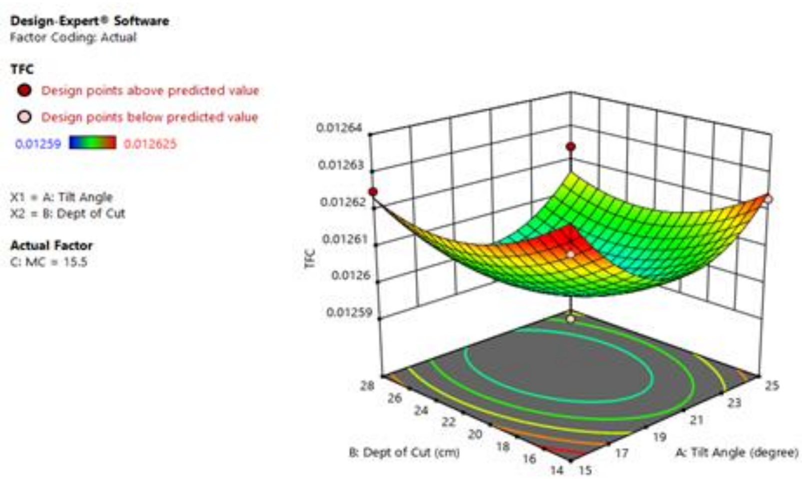

Figure 1 The response surface plot of the theoretical field capacity of the disc harrow

Figure 1 demonstrates the response surface plot of the theoretical field capacity of the disc-harrow. Results of this plot revealed that the theoretical field capacity increases with the increase in the tilt angle, attaining the highest point of 0.012626 at cutting depth of 28cm under 15^o tilt angle load.

Figure 2 illustrates the differentiation betwixt the predicted and real values of the theoretical field capacity of the disc harrow, which was specifically used to validate the models. Additionally, Figure 2 presents the validation of the quadratic model's suitability through the normal distribution plot of the theoretical field capacity residuals, along with the plot comparing predicted and experimental theoretical field capacity. The plotted points closely align with the line of best fit, indicating that the theoretical and actual field capacities are within an acceptable range. The model equations did not significantly overestimate or underestimate the experimental results, suggesting that the predictions remained within a reasonable margin. This implies strong interactions and a sufficient correlation among the independent variables, indicating that the response model for the theoretical field capacity effectively captures the overall variability in the response.

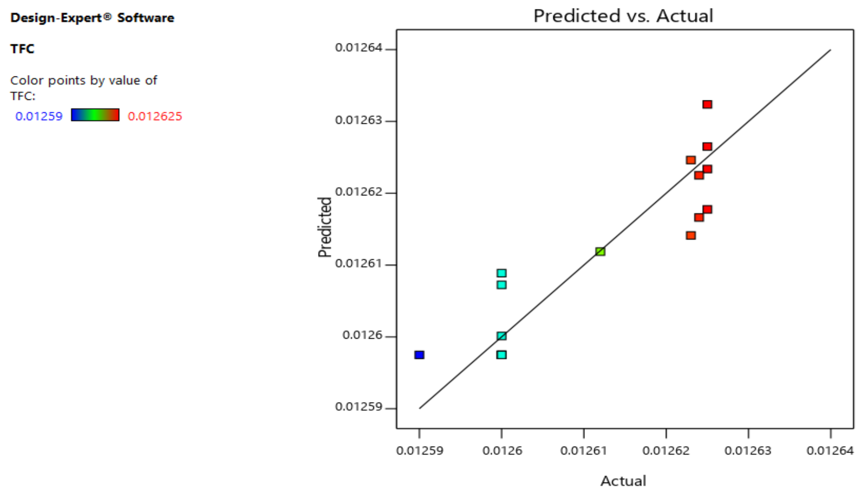

Figure 2. Predicted versus actual value plot of the theoretical field capacity of the disc harrow

2.2.2 Effective Field Capacity (EFC)

Table 5 presents the ANOVA results for the Quadrant model of EFC of the disc-harrow. The Model F- statistics/value of 2.14 alludes that the model is inconsequential when differentiated from the noise, with an 18.31% possibility that an F-statistics/value of this immensity may emerge from inconsistency/arbitrary change. P-statistics/values beneath 0.0500 demonstrate that the model terms are statistically significant, with A² being a notable term in this instance. Conversely, P-statistics/values beyond 0.1000 insinuate that the model terms lack significance. Assuming there are several inconsequential model terms (not those necessary for maintaining the grade/level), simplifying the model may boost its conduct. The Lack of Fit F-statistics/value of 2.74 shows that the lack of fit is inconsequential relative to pure error, with a 21.50% chance that such a Lack of Fit F-statistics/value can be ascribed to noise. A non-significant lack of fit is advantageous, as it indicates that the model fits well.

Table 5 ANOVA for Quadratic model

Source	Total of Squares	df	Average Square	F-value	p-value	
Model	0.0034	9	0.0004	2.14	0.1831	Inconsequential
A-Tilt Angle	0.0001	1	0.0001	0.7339	0.4245	
B-Dept of Cut	0.0001	1	0.0001	0.6544	0.4494	
C-MC	4.500E-08	1	4.500E-08	0.0003	0.9878	
AB	4.000E-08	1	4.000E-08	0.0002	0.9885	
AC	0.0003	1	0.0003	1.47	0.2712	
BC	0.0003	1	0.0003	1.52	0.2633	
A^2	0.0024	1	0.0024	13.46	0.0105	
B^2	0.0003	1	0.0003	1.44	0.2753	
C^2	2.500E-09	1	2.500E-09	0.0000	0.9971	

Residual	0.0011	6	0.0002			
Lack of Fit	0.0008	3	0.0003	2.74	0.2150	Inconsequential
Pure Error	0.0003	3	0.0001			
Cor Total	0.0045	15				

Final Equation in Terms of Actual Factors

$$EFC = 0.453217 + 0.044994T + 0.011101D + 0.011441M - 2.857E\text{-}06TD - 0.000323TM - 0.000235DM - 0.000978T^2 - 0.000163D^2 - 1.0E\text{-}06M^2 \quad (7)$$

Table 6 presents the Fit Summary for the EFC of the disc harrow. The results indicated in this table suggest that the quadrate model is suitable for prediction/forecasting the effective field capacity of the harrow.

Table 6 **Fit Rundown of Effective Field Capacity**

Source	**Sequential p-value**	**Lack of Fit P-value**	**Modified R^2**	**Predicted R^2**	
Linear	0.8720	0.1172	-0.1813	-0.7078	
2FI	0.7370	0.0848	-0.3779	-2.1003	
Quadratic	**0.0458**	**0.2150**	**0.4066**	**-1.8951**	Suggested
Cubic	0.2150		0.6826		**Aliased**

Table 7 Sequential Model Total of Squares for the Harrow

Source	**total of Squares**	**df**	**Average Square**	**F-value**	**p-value**	
Average vs Total	19.57	1	19.57			
Linear vs Average	0.0002	3	0.0001	0.2325	0.8720	
2FI vs Linear	0.0005	3	0.0002	0.4294	0.7370	
Quadratic vs 2FI	**0.0026**	**3**	**0.0009**	**4.97**	**0.0458**	Suggested
Cubic vs Quadratic	0.0008	3	0.0003	2.74	0.2150	**Aliased**
Residual	0.0003	3	0.0001			
Total	19.58	16	1.22			

Table 7. shows the Sequential Model total of Squares for the disc harrow being analyzed. The results in this table further indicate that the quadrate model is the ideal fit for estimating the harrow's performance.

Figure 3 display the comparison betwixt the predicted and real values of the effective field capacity for the disc harrow, which was specifically used to validate the models. Additionally, Figure 4.5 presents the validation of the quadratic model's suitability through the normal possibility plot of the effective field capacity residuals, along with the comparison of predicted versus experimental theoretical field capacity. The plotted points align closely with the line of best fit, indicating that the EFC and the experimental or actual EFC are within an acceptable range. Overall, the model equations did not significantly overestimate or underestimate the experimental results, suggesting that the predictions are reliable. This implies strong interactions and a good correlation among the independent variables, as well as evidence that the response model for theoretical field capacity can effectively account for the overall variability in the response.

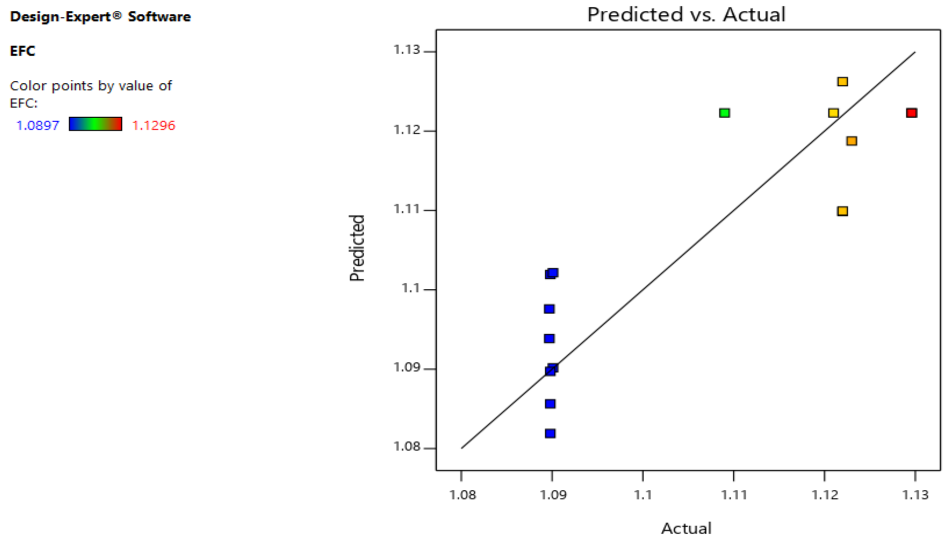

Figure 3. The predicted versus actual value plot for the effective field capacity of the disc harrow

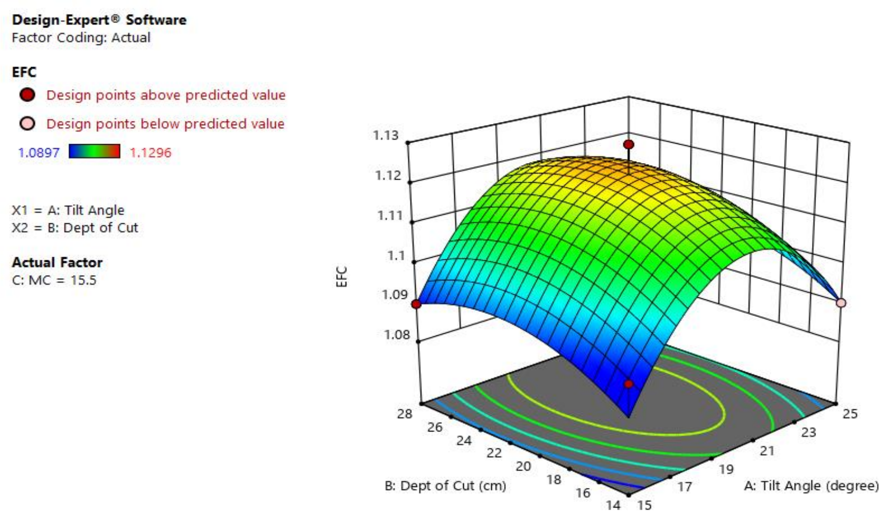

Figure 4 shows the response surface plot illustrating the effective field capacity of the disc harrow.

Figure 3 shows the predicted versus actual value plot for the effective field capacity of the disc harrow. Figure 4 presents the response surface plot for the effective field capacity of the disc harrow. The results from the surface plot indicate that the EFC decreases as the tilt angle increases, while it increases with a greater depth of cut of the harrow.

2.2.3 Field Efficiency (FE) of the disc harrow operation

Table 8 provides ANOVA results for the quadrant model assessing the harrow's FE. The Model F-statistics/value of 3.68 indicates a 6.34% chance that an F-statistics/value of this size can arise from inconsistency. P-values beneath 0.0500 imply that the model terms are significant, with A and A^2 being the significant terms in this analysis. Conversely, P-values exceeding 0.1000 indicate that the model terms are not significant. When multiple model terms are inconsequential (not those required for grade/level), simplifying the model may boost its accuracy. The Lack of Fit F-statistics/value of 0.11 shows that the lack of fit is inconsequential when contrasted to pure error, with a 95.13% likelihood that such a Lack of

Fit F-value could be attributed to noise. An insignificant lack of fit is preferable, as it is inferred that the model is suitable. Table 8 presents the ANOVA for the quadratic model of the harrow's field efficiency.

Table 8. Source	**Total of Squares**	**df**	**Average Square**	**F-value**	**p-value**	
Model	10.92	9	1.21	3.68	0.0334	consequential
A-Tilt Angle	3.84	1	3.84	11.63	0.0143	
B-Dept of Cut	0.4950	1	0.4950	1.50	0.2664	
C-MC	0.2701	1	0.2701	0.8190	0.4003	
AB	0.5550	1	0.5550	1.68	0.2422	
AC	0.2550	1	0.2550	0.7733	0.4130	
BC	0.0529	1	0.0529	0.1604	0.7027	
A^2	5.42	1	5.42	16.43	0.0067	
B^2	0.0390	1	0.0390	0.1183	0.7426	
C^2	0.0018	1	0.0018	0.0055	0.9434	
Residual	1.98	6	0.2275			
Lack of Fit	0.1891	3	0.1138	0.1057	0.3413	consequential
Pure Error	1.79	3	0.5966			
Cor Total	12.90	15				

Table 9 arrays the Fit Summary of the model regarding the field efficiency of the disc harrow. The results indicate that a quadratic model was developed to predict the field efficiency of the harrow.

Table 9 Sequential Model Total Squares for Field Efficiency

Source	**Total Squares**	**df**	**Average Square**	**F-value**	**p-value**	
Average vs Total	1.254E+05	1	1.254E+05			
Linear vs Average	4.60	3	1.53	2.22	0.1387	
2FI vs Linear	0.8630	3	0.2877	0.3481	0.7916	
Quadratic vs 2FI	**5.46**	**3**	**1.82**	**5.52**	**0.0368**	**Suggested**
Cubic vs Quadratic	0.1891	3	0.0630	0.1057	0.9513	Aliased
Residual	1.79	3	0.5966			
Total	1.254E+05	16	7837.37			

Table 10 portrays the Fit Statistics for the model assessing the FE of the harrow. The Predicted R^2 value of 0.5188 is in accord with the modified R^2 of 0.6166, as the discrepancy is under 0.2. Adequately measures the signal-to-noise ratio, with a preference for ratios exceeding 4. The model achieves a ratio of 5.663, indicating a strong signal and making it appropriate for investigating the design space. Table 10 Fit Statistics of model for field efficiency of the harrow.

Table 10. portrays the Fit Statistics for the model assessing the FE of the harrow.

Std. Dev.	0.5743	**R^2**	0.8466
Average	88.52	**Modified R^2**	0.6166
C.V. %	0.6487	**Predicted R^2**	0.5188
		Adeq Precision	5.6634

The last equation expressed in terms of the actual factors

FE = +63.14641+2.38055T +0.041750D +0.122600M -0.010643TD -0.0101TM

$+0.003286DM - 0.04655T^2 + 0.002015D^2 - 0.00085M^2$ (8)

The equation/expression based on key contributors can help forecast responses for specific levels of each factor, using the original units for those factors. However, this expression shouldn't be used to evaluate the proportional effect of each factor, since the coefficients are normalized according to the units of each factor, and the intercept is not centered within the design space. Figure 5 illustrates the forecasted versus actual value plot for the FE of the disc harrow, which was specifically used to validate the models. Additionally, Figure 4.9 demonstrates the validation of the quadratic model's suitability through the normal probability plot of the draft power residuals, as well as the plot comparing predicted and experimental field efficiency. The plotted points closely align with the line of best fit, indicating that the drawbar power and the experimental field efficiency are within an acceptable range. Overall, the model equations did not significantly overestimate or underestimate the experimental results, suggesting that the predictions remained within a reasonable range. This reflects strong interactions and sufficient correlation among the independent variables, indicating that the response model for field efficiency effectively captures the overall variability in the response.

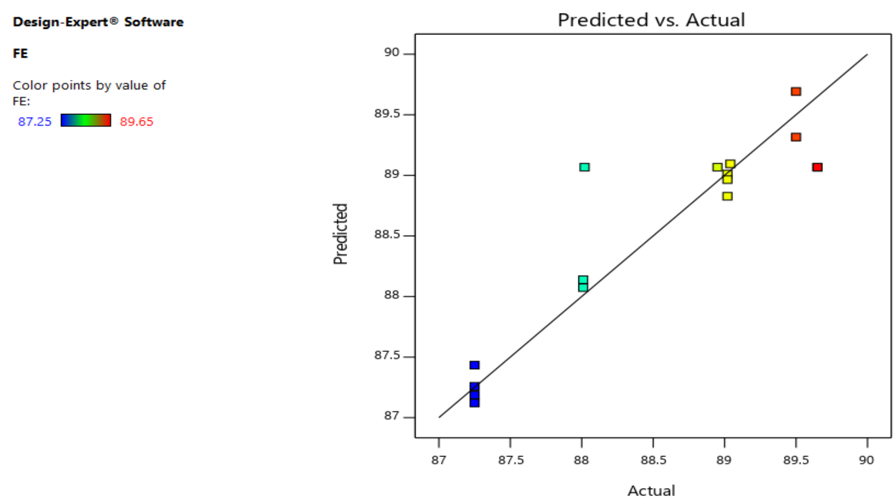

Figure 5. illustrates the predicted versus actual value plot for the field efficiency of the disc harrow.

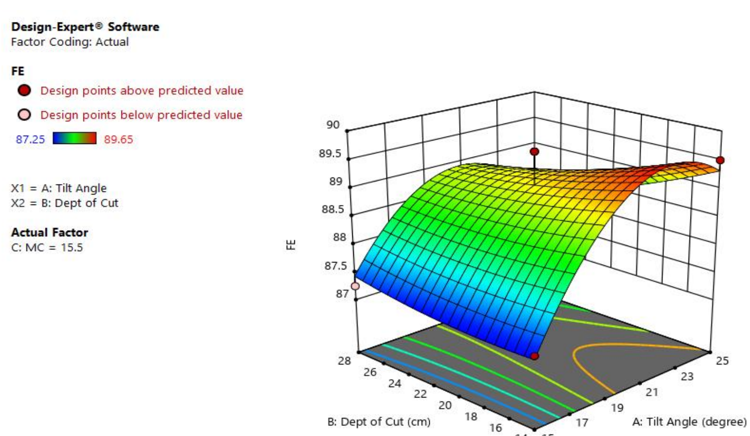

Figure 6 The response surface plot of the field efficiency of the disc harrow

Figure 6 illustrates the response surface plot depicting the relationship between field efficiency (FE), tilt angle and depth of cut during disc harrow operation. The plot indicates that as the tilt angle increases, the field efficiency tends to decline, likely due to reduced soil penetration and increased slippage. Conversely, an increase in the depth of cut leads to improved field efficiency, suggesting that deeper tillage enhances soil turnover and improves traction, thereby optimizing the harrow's performance.

5. Conclusion

The study on how operational angles and cutting depth affect the production and output of a disc harrow on sandy loam soil in Umuahia was successfully carried out. The findings indicated that the harrow achieved its highest field efficiency of 90.42% when operated at a tilt angle of 20 degrees and a penetration depth of 21 cm. Under this setting, the harrow's theoretical field capacity and effective field capacity were 0.012597 ha/hr and 1.139 ha/hr, separately, with a fuel usage rate of 0.33 l/hr. The lowest field efficiency recorded was 86.48%, which occurred at the same angle of 20 degrees but with a cutting depth of 14 cm. In this case, the theoretical and effective field capacities were both 0.012601 ha/hr, and the fuel consumption rate was 0.34 l/hr. Additionally, the harrow exerted an average draft force of 5.61 kN and drawbar power of 10.90 kW while consuming fuel at a rate between 0.20 l/hr and 0.37 l/hr.

Due to variations in soil conditions across different environments, further research is needed to assess disc harrow performance on diverse soil types. Additionally, studying other tillage tools will help optimize soil preparation, enhance productivity, reduce costs, and improve equipment efficiency.

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