



## MODELING OF FIELD EFFICIENCY OF A TINE HARROW ON CLAY LOAM SOIL IN ABIA STATE

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### ARTICLE INFORMATION ABSTRACT

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This study was conducted to model the field efficiency of tine harrow on clay-loam soil in Abia State using response surface methodology. This is to assist farmers and operators of the implement to evaluate and probably decide on appropriate harrowing implement depending on the type of soil for their seed bed preparation for efficient production at negligible energy loss. The operational speed (6-8 km/hr.), effective working width (60- 180 cm) and depth of cut (5-10 cm) were adopted as independent factors for the field efficiency study of the tine harrow. Results revealed that the highest field efficiency of 98.40% was recorded when the harrow was operated at the depth of 10cm, speed of 6km/hr. and effective working width of 180cm. The quadratic model was significant ( $P < 0.05$ ) for the evaluation of field efficiency of the harrow. Results revealed that the coefficient of determination,  $R^2$  was 0.91, which indicated good relationship among the variables, also an indication that the response (field efficiency) could describe 91% of the overall erraticism within the response. Result of simulation achieved revealed that the field efficiency fall within the trial range. The predicted  $R^2$  (0.77) was compatible with the adjusted  $R^2$  (0.80) meaning that the investigational data fitted well.

### 1.0 Introduction

Tillage is an alteration of soil structural conditions by mechanical forces such as shearing or compressing, or tearing. Kepner *et al.* (2012) defined tillage as the manipulation of soil in order to develop a desirable soil structure for a seedbed or root bed - granular structure is desirable to allow rapid infiltration and good retention of rainfall, to provide adequate air capacity and exchange within the soil, and to minimize resistance to root penetration. It is also carried out to control weeds and remove unwanted plants (thinning). It could help in minimizing soil erosion by following certain practices such as contour tillage and managed plant residues. A good seedbed is generally considered to imply fine particles and greater firmness in the vicinity of seeds. According to K'Owino (2010) about 80% of the Nigerian population live in rural areas and derive their livelihood from agriculture. Even for the urban poor, a majority of them make a living on agricultural related activities. The sector is therefore the main source of national income and employment creation for over 80% of the population and contributes to poverty reduction and food security. Small-scale farmers, mainly in the high potential areas, dominate Kenya's agriculture. He further established in his study about the adoption of conservation agriculture that use of quality inputs and equipment such as hybrid seed, fertilizers and pesticides and machinery by the sub-sector is very low. Therefore, to increase and or sustain

productivity in the sub sector, there is need for enhanced efforts to encourage farmers to adopt modern farming practices that entail sustainable land development for food security.

It is recognized that application of power saving methods can make effective contributions to economy (Sessiz *et al.*, 2010), hence the need to do proper matching of implements and operation at optimal depths and speeds of tillage.

Several agricultural operations are required for different purposes, namely, harrowing, seeding, cultivating, and spraying. Different operations also need special equipment. Bell (2016) reported that tine harrow, disc, chisel, rotary, and subsoiler harrows are used as main implements for secondary tillage operation.

Tillage is the agricultural preparation of soil by mechanical agitation of various types, such as digging, stirring, and overturning (Gatea, 2013). Tillage can be classified as primary and secondary tillage. It is normally conducted when the soil is wet enough to allow plowing and strong enough to give reasonable levels of traction. This can be immediately after the crop harvest or at the beginning of the next wet season. Primary tillage consists of cutting, breaking, returning, and popularizing soil by implements (Ahaneku *et al.*, 2019). (Gatea, 2013) reported that primary tillage operation is used for several objectives. First, it is for cutting soil and seedbed preparation. Second, it is to destroy activities and breeding of insects and pests. Thirdly, it is to control weeds and fertile soil by converting crop residues. Finally, it is to reduce water and wind erosion also to increase soil aeration and the infiltration rate. The greatest amounts of fuel are consumed by tine harrow, disc, and chisel harrows, (Khadr, 2018; Stajniko *et al.*, 2019). The amount of fuel consumption by tractor engines during tillage operation depends on several factors including harrowing depth, operational speed, etc. (Godwin, 2017). There is a liner correlation between the amounts of fuel consumption and harrowing depth, due to increasing soil resistance and volume of soil. Similarly, Moitzi *et al.* (2013) observed that the amount of fuel consumption increased significantly when the harrowing depth increased.

Rashidi *et al.* (2013) reported that the correlation between depth of harrowing and performance of tractor is non-linear because the mass of soil per cutting unit increases and a higher power is required to pull and operate the implements. In other words, greater amount of power requires if depth of harrowing will increase. For the same purpose, Moeinfar *et al.* (2014) used a chisel harrow for secondary tillage at three levels of harrowing depth and reported that the higher level of depth had the greatest influence on increasing draft force. Therefore, the greatest power should be applied to operate primary tillage implements at a deeper level.

Rashidi *et al.* (2013) studied effects of tractor forward speed, depth of harrowing, and soil moisture content on the performance of tractor in clay soil texture and have discovered that the performance of tractor significantly increased when tractor forward speed increased. Similarly, Hunt (2001) indicated that the tine harrow requires higher power because it pulverizes soil to the higher level.

Increase in agricultural mechanization in the country has caused varied imports of implements and sizes of tractors though they have not been based on data on power requirement that is matched to our soils and field conditions. Even after buying these machineries, at farm level implements are paired to tractors without considering the power output from the tractor and

power demand by implements. Farm machinery managers, farmers, consultants and policy makers need to rely on power requirements and performance data while selecting tillage implements for tillage operation. Availability of tillage implement power requirements for different soils and conditions, and performance data is important for efficient farm machinery management. Therefore, there is need to upgrade the tillage implements for selection and matching of tractors for local soils and conditions that would help farmers and managers to match tractors and implements carrying out tests for different soils and soil conditions with common tillage implements.

The objective of this study is to determine the effect of harrow depth, speed of operation and effective cutting width on field efficiency of a tine harrow. Tillage of soil with minimum energy consumption can be achieved by breaking the bonds between soil aggregates with tensile deformations. Values of machine capacities are applied in scheduling field operations, its power units and labor as well as to determine implement and machine operating costs. Different machines have different field efficiencies, though depending upon the system of operations, soil type conditions and the system of management. This condition improves field efficiency but it is not, of course, a desirable operating condition. The proposed implement includes a tine harrow. Thus, the destruction of a pre-stressed soil formation due to tensile stresses caused by the mutual arrangement of working elements and the interconnection of machine operation modes contributes to the reduction of energy consumption.

## **2.0 Research Methodology**

### **2.1 Study Area**

The study was conducted in Ikwuano L.G.A of Abia state Nigeria, with a population of about 3,920,208 million. It is located within latitude  $5^{\circ} 20'$  and  $5^{\circ} 30'$  N, of equator and longitude  $7^{\circ} 40'$  and  $7^{\circ} 50'$  E of the Greenwich meridian and characterized by sub-humid eco-climate. (2500-3000) mm per annum, average annual temperature of  $27^{\circ}\text{C}$  and relative humidity range of 80-90% in the wet season (NRCRI, 2016). Dry season start in November and ends in March while rainy season lasts from April to October. The inhabitants of Ikwuano are predominantly farmers. The L.G.A comprises six agricultural zones (Ariam, Umuariaga, Amaoba, Amaimeand Amawom and Oboro).

### **2.2 Experiment Site**

The experiment was performed at Michael Okpara University of Agriculture, Umudike, Farm site. Michael Okpara University of Agriculture, Umudike is located in Ikwuano LGA of Abia state, the soil texture of the site is a clay- loam with 65% sand, 19% clay, and 16% silt. The total area of the site is  $1800\text{ m}^2$  with 60 m length and 30 m width.

### **2.3 Tractor and Implement Used for the test.**

A Massey Ferguson tractor of model MF430E and capacity 55.2 kW, with 3- point hitch systems and age of 1 year from date of first hand purchase was used for the test. This tractor was selected for the study because it recorded the highest pulverizing efficiency with the tillage implements as compared to tractors that are mostly used in south- east Nigeria for field operations (Oduma and Oluka, 2017). The hitched implements studied is tine harrow.

## 2.4 Determination of soil physical

Some soil physical characteristics such as moisture contents, bulk density, soil structure, texture, porosity, that influence machinery performances, were determined using the method adopted by Oduma et al. (2019).

## 2.5 Experimental procedure

The field operation tests were conducted using the methods adopted by ( Oduma et al. 2019) in which the harrowing operations were generally performed longitudinally with the implement selected, width at selected forward speeds and cutting depth, the distance travelled and the corresponding time taken to complete the working distance were noted; and the field efficiency, of the implements was determined as stated below.

## 2.6 Determination field efficiency

The field efficiency was determined from the expression suggested by Kepner et al. (1982) as adopted by Oduma et al. (2018).

$$\epsilon = \frac{100 \times T_e}{T_t} \quad (1)$$

Where,  $\epsilon$  is the field efficiency (%)

$T_e$  = the actual working (productive) time (h)

$T_t$  = the total working time (h)

$T_t = T_e + T_d$ ; and  $T_d$  is the delay or idle time (h).

## 2.7 Experimental design

The experimental design adopted in the research work was a three level – three factor full factorial design. The experiment consists of three factors which were varied at three levels of tillage depths which include 5, 8, 10 cm, three levels of effective working widths of 60, 120 and 180 cm and three levels forward speeds (6, 7, and 8 km/hr). Central Composite Response Design which gives 17 test runs was performed for each sample using Equation 2 (Umani et al., 2019).

$$N = 2^k + 2k + n_c \quad (2)$$

Where,  $N$  = number of test runs,  $k$  = experimental factors and  $n_c$  = Centre point

In order to obtain the desired data, the range of values of every one of the 3 factors ( $k$ ) was evaluated (Table 1). Working width, operational speed and tillage depth were adopted as independent factors for the field efficiency of the tine harrow. The response selected was the field efficiency, %. Four repetitions of the center points were adopted in order to predict a well and concise approximation of errors; and the field experiments were conducted in randomized form.

**Table 1:** Actual values, codes and levels of the test variables for design of experiments

Factors	Symbols	Codes and levels		
		-1	0	1
Working width (m)	A	60	120	180
Tillage Depth (cm)	B	5	8	10
Operational speed (km/hr)	C	6	7	8

## 2.8 Response Surface Methodology (RSM)

The Design Expert of version 11.0 was employed to design the experiment, analyze data obtained, optimize the practical factors and produce models for the estimation of the field efficiency of the tine harrow. The quadratic, cubic, linear and two factorial interaction (2FI) models were designated to analyze the field efficiency of the implement; and the models were fitted to the generated experimental data.

Data obtained were analyzed using the Response Surface Methodology (RSM) to fit the quadratic polynomial equation gotten from the Design Expert Software as expressed in Equation (3) according to Chih et al. (2012).

$$Y = \beta_0 + \sum_{i=1}^2 \beta_i X_i + \sum_{i=1}^2 \beta_{ii} X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^2 \beta_{ij} X_i X_j \quad (3)$$

where:  $Y$  = Response;  $\beta_0$  = constant term;  $\sum_{i=1}^2 \beta_i$  = Summation of coefficient of linear terms;  $\sum_{i=1}^2 \beta_{ii}$  = Summation of quadratic terms;  $\sum_{i=1}^2 \sum_{j=i+1}^2 \beta_{ij}$  = summation of coefficient of interaction terms;  $X_i X_j$  = independent variables.

Also, the multiple regressions were adopted to fit the coefficient of the polynomial model to enable the response variables be correlated with the independent variables. The reliability of fit of the model, the discrete and interaction effect of the tillage parameters (effective working width, operational speed and depth of tillage) on the responses (field efficiency) of the implement were evaluated using analysis of variance (ANOVA). Data attained were also subjected to statistical analysis to obtain the effects of the effective working width, operational speed and tilling depth and their interactions on the field efficiency of the implement at  $\alpha = 0.05$  using Minitab 17.0.

## 3.0 Results and Discussion

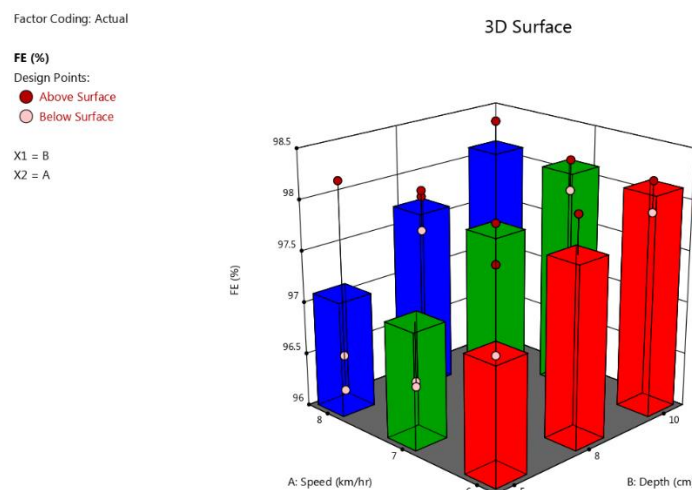
### 3.1 Field efficiency of the tine harrow

Table 2 presents the randomized design layout of three levels –three factors full factorial composite design of experiment with actual and predicted values of energy requirements of tine harrow. This table presents the relations between the trial factors (working width, operational speeds and harrowing depths) with the field efficiency of the harrow. The values of actual field efficiencies achieved in the course of the tillage operation vary from 91.70 – 98.50% for the range of operational speed (6 – 8 kmh<sup>-1</sup>), harrowing depth between 10 – 30cm and working width range from 60 – 180 cm. Results specified that the highest field efficiency of 98.50% was obtained when the harrow was operated at the cutting depth of 20cm under operational speed of 7 kmh<sup>-1</sup> and working width of 120 cm. While the least field efficiency of 91.70 % was achieved at cutting depth of 30cm under working width of 180 cm and operational speed of 7 kmh<sup>-1</sup>. It was frequently discovered that at different operational speeds and effective working width, the field efficiencies increase with the increase in harrowing depth and increases to peak point of 98.50% at operational speed of 7 kmh<sup>-1</sup> and at depth of 20cm under effective working width of 120 cm. The field efficiency of the implement decreases by 6.15% when harrowing at depth of 10 cm and 3.05% at depth of 30 cm irrespective of the effective width of cut and operational speed. This is in line with the observations of Oduma et al (2022).

**Table 2:** Randomized design layout of three levels –three factors full factorial composite design of experiment with actual and predicted values of field efficiency of tine harrow

Run order	Coded factors			Actual factors			Field efficiency, %	
	A	B	C	Harrowing depth (cm)	Effective working Width (cm)	Operational speed (km/hr)	Actual values of Field efficiency	Predicted values of Field efficiency
1	-1	0	-1	5	60	7	90.95	89.22
2	1	1	0	10	180	7	97.95	91.70
3	-1	1	0	10	60	7	98.25	92.40
4	0	-1	1	5	120	6	97.90	90.30
5	0	0	0	5	120	6	97.90	90.30
6	0	0	0	10	120	6	98.20	92.20
7	0	1	1	8	120	7	98.11	88.98
8	1	1	0	10	180	6	98.40	87.40
9	0	0	0	8	120	8	97.84	93.23
10	1	0	-1	5	180	8	96.15	85.72
11	0	-1	-1	8	120	8	98.11	87.93
12	1	0	1	10	180	6	97.90	91.48
13	0	1	-1	10	120	6	97.90	90.30
14	-1	-1	0	8	60	6	97.80	87.43
15	-1	0	1	8	60	7	98.11	88.11
16	0	0	0	8	120	6	97.80	88.43
17	0	0	0	5	120	7	96.50	91.35

Figure 1 is the response surface plot of harrowing depth, effective working width and operational speed against field efficiency of tine harrow showing the relationship between the factors and the response. Results of this figure showed that the highest field efficiency of 98.50% was observed at speed of 7 kmh<sup>-1</sup> at harrowing depth of 20 cm and effective working width of 120 cm. The highest field efficiency achieved at operational speed of 7 kmh<sup>-1</sup> is slightly higher than the operational speed of harrow and was attributed to the lower tractive and draft force associated with secondary tillage operation after the soil has been acted upon by the plough which is related with low working speed enabling the implement to pierce deep and collapse the resistance force offered by the soil to implement penetration.



**Figure 1.** Response surface plot of harrowing depth, effective working width and operational speed against field efficiency of tine harrow.

### 3.2 Model assessment of tine harrow efficiency

The field efficiency of the tine harrow in clay -loam soil depends on the results illuminating the significant difference for combination of the speed, effective working width and cutting depth of the harrow. The model coefficient, effect, contribution, test of lack of-fit and the significance of the factors and their interactions on the field efficiency were evaluated according to Oduma et al. (2022), Umani et al. (2019) and Fakayode et al. (2016). A quadratic model was significant for the response (Table 4), thus,  $P < 0.05$ ; indicating that the significant model term was achieved at 95% significance level. The quadratic model equation obtained to predict the field efficiency in regard to the independent variables or operating factors (speed, effective working width and harrowing depth) is as stated in Equation 4.

$$FE = 132.20 - 0.85A - 0.17B - 23.62C + 0.006AB + 0.1AC + 0.10BC - 0.01A^2 - 0.0001B^2 + 1.63C \quad (4)$$

Where FE = field efficiency, %

A = harrowing depth of the harrow, cm

B = effective working width of the disc harrow, cm

C = operational speed,  $\text{kmh}^{-1}$

The quadratic model as gotten in this research work is in proportion to the findings of Oduma et al. (2019) in their study of the development of empirical regression equations for predicting the performances of disc plough and harrow in clay-loam soil and Oduma et al. (2022). The p-value (0.0055) of the mode as presented in Table 5 is less than the designated  $\alpha$ - level of 0.05 indicating that the model is significant. Thus, the interactions of the operating factors (speed, effective working width and harrowing depth) have significant effects on the field efficiency of the implement. Hence, the model term p-values of 0.0003, 0.0515 and 0.0072 which are less than the selected  $\alpha$ - level of 0.05 stipulate that the model terms are significant. Thus, AB (interaction of A-harrowing depth and B-effective working width), AC (interaction of A-harrowing depth and C-operational speed) and  $C^2$  are significant model terms as displayed in Table 3. This result agrees with the judgments of Ajav and Adewoyin (2012). Nevertheless, it is not statistically consistent with the results of Saeed et al. (2017) in their research of performance of tractor and tillage implements in clay Soil wherein the p-value of the field efficiency attained is 0.00 at  $p \leq 0.05$  and could be credited to the variances in the soil and/or ecological/environmental conditions of diverse study regions as indicated by Bako et al. (2021). Finally, The Lack of Fit F-value of 0.1114 (Table 5) implies that the Lack of Fit is not significant relative to the pure error. However, there is a 94.89% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit according to Umani et al. (2019) is good since the model is required to fit.

**Table 4:** ANOVA of model summery statistics

Source	Sequential p-value	Lack of Fit p-value	Adjusted R <sup>2</sup>	Predicted R <sup>2</sup>	
Linear	0.9598	0.0815	0.6272	-0.9574	
2FI	0.0094	0.2649	0.4950	-0.3112	
Quadratic	0.0334	0.9544	0.7331	0.7164	Suggested
Cubic	0.8590		0.6899		Aliased

**Table 5.** ANOVA of response surface quadratic model for field efficiency of tine harrow

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	54.01	9	6.00	8.25	0.0055*
A-Tillage Depth	0.0595	1	0.0595	0.0818	0.7831 <sup>NS</sup>
B-Width	1.35	1	1.35	1.86	0.2148 <sup>NS</sup>
C-Speed	1.64	1	1.64	2.25	0.1771 <sup>NS</sup>
AB	31.98	1	31.98	43.97	0.0003*
AC	4.00	1	4.00	5.50	0.0515*
BC	1.42	1	1.42	1.95	0.2056 <sup>NS</sup>
A <sup>2</sup>	3.50	1	3.50	4.81	0.0643
B <sup>2</sup>	0.5663	1	0.5663	0.7786	0.4068 <sup>NS</sup>
C <sup>2</sup>	10.19	1	10.19	14.01	0.0072*
Residual	5.09	7	0.7273		
Lack of Fit	0.3927	3	0.1309	0.1114	0.9489 <sup>NS</sup>
Pure Error	4.70	4	1.17		
Cor Total	59.10	16			

\*Significant; NS= Not Significant

### 3.3 Validation of the Model of the field efficiency of the harrow

Results of the validation of the model equation are shown in Table 6. According to the results, the model is significant. The coefficient of determination,  $R^2$  (0.9139) shows awesome alliances amid the independent variables, which means that the response model can elucidate 91.39 % of the full changeability in the response (Oduma et al., 2022; Umani et al., 2019).

Results of the simulation (Table 6) of the quadratic model achieved in the study indicated that the field efficiency fall within the experimental array. The Predicted  $R^2$  (0.7695) is reliable with the Adjusted  $R^2$  (0.8031); thus, the difference is less than 0.2 indicating that the trial data fitted very well, as posited by Kothari (2014). The adjusted  $R^2$  obtained is compatible with the  $R^2$  (0.9615) as obtained by Oduma et al. (2020). The adequacy Precision (10.375) ratio obtained is greater than 4 is appropriate, indicating an acceptable signal and that the model equation might be espoused to navigate the design space.

**Table 6.** Coefficient of determination,  $R^2$  for validation of model term

Std. Dev.	0.8528	$R^2$	0.9139
Mean	96.19	Adjusted $R^2$	0.8031
C.V. %	0.8867	Predicted $R^2$	0.7695
		Adeq Precision	10.3749

### 4.0 Conclusion

The study was carried out to obtain data on the effect of harrowing depth, speed of operation and effective cutting width on field efficiency of a tine harrow on clay loam soil in Abia State, for suitable selection, operation and matching of the field machineries. From the findings in the research work, the following conclusions can be made about the study: Results obtained in this study will aid in proper selection, management and operation of the farm machinery based on soil type/condition and operational speed for better performance. Finally, owing to differences



in soil type/conditions among different agricultural areas; it is therefore recommended that studies of this kind should be carried out in every agricultural zone to provide data on machine/implement performances based on soil types for increased production.

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