



EFFECT OF HARROWING DEPTH, SPEED AND EFFECTIVE CUTTING WIDTH ON FUEL CONSUMPTION RATE OF A TINE HARROW ON CLAY LOAM SOIL IN ABIA STATE

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ARTICLE INFORMATION ABSTRACT

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This research was conducted to study the effect of harrowing depth, speed and effective cutting width on fuel consumption rate of a tine harrow on clay loam soil in Abia state to aid farmers to examine and choose the right harrowing implement based on the soil type for an effective and munificent production. The operational speed, effective working width and cutting depth were taken as factors for the study of the fuel consumption rate. The results revealed that the highest fuel consumption rate of 7.5l/ha was noted when the harrow worked at the cutting depth of 10 cm and a speed of 6 km h⁻¹ and width of 180cm (when working at full width) while the lowest fuel consumption rate of 6.5l/ha was achieved at a speed of 6 km h⁻¹, working width of 120cm and a cutting depth of 5 cm. The quadratic model was significant for the response ($P < 0.05$). The results indicated that the coefficient of determination (R^2) was 0.98, which specified the high correlation among the factors. The predicted R^2 (0.97) was consistent with the adjusted R^2 of 0.95. The adequacy precision of 31.000 showed a suitable indicator and that the model could navigate the design space. The optimization process with the optimal operating factor of operational speed of 6.15 km/hr, working width of 180cm and tillage depth of 30cm and the optimum fuel consumption rate and the desirability of 7.17 l/ha and 0.697 were respectively obtained.

1.0 Introduction

Agricultural machinery including tractor is considered as one of the most important aspects for operating most agricultural operations and duties (Bell, 2016). Adewoyin and Ajav (2013) reported that agricultural productions were significantly improved since tractors have been used for agricultural operations. The tractor can be described as a power source in the agricultural fields to operate a variety of implements (Yahya, 2016). 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 can be defined as 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) posited 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; Stajanko 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. (2016) 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. Furthermore, all functions of secondary tillage cannot be achieved by other types of harrow compared to the tine harrow.

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 fuel consumption rate and field efficiency of a tine harrow.

The 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 Materials and Method

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°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 Experimental 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 sandy loam with 65% sand, 19% clay, and 16% silt. The total area of the site is 1800 m² with 100 m length and 30 m width. Tractor forward speeds will be determined by selecting a particular gear that will give the desired speed. The meter rule will be placed from the bottom to the surface of the harrowed land to measure harrowing depth, Time will be determined with stop watch setting at zero before each operation. Topping up the tank method of determining the quantity of fuel used will be adopted in the determination of tractor fuel consumption.

2.3 Specifications of Tractor and Implement Used for the test.

A Massey Ferguson tractor of model MF430E and capacity 55.2 kW, with 3- point hitch systems 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, the same operator was used to operate the machine throughout the test with three replications of each operation to ensure minimal variation in the operation skill and style throughout the study (Oduma et al., 2018).

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 tests were conducted using the methods adopted by (Oduma et al. 2019) in which the harrowing operations were generally performed longitudinally at selected, width, forward

speeds and cutting depth. The area worked and the corresponding time taken to complete the area were noted; and the fuel consumption rate was determined as stated below.

2.6 Fuel consumption

The fuel consumption was evaluated as adopted by Oduma et al. (2018).

$$F_c = \frac{\text{Amount of litre used}}{\text{Total kilometer traveled}} \quad (1)$$

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 Energy requirement and field efficiency of the plough. The response selected was the drawbar power, kW. 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

3.1.1 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 draft force and drawbar power of the disc plough. The quadratic, cubic, linear and two factorial interaction (2F1) models were designated to analyze the draft force and drawbar power of the implement; and the models were fixed 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; β_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 (Energy requirement and 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 drawbar power of the implement at $\alpha = 0.05$ using Minitab 17.0.

3.0 Results and Discussion

3.1 Fuel consumption rate (Energy consumption) of harrow

Table 2 showed 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. The harrowing operation which was performed at selected operational speeds, working width and harrowing depths, at average soil moisture content of 12.5% and the results of the energy requirement of the disc harrow were shown in Table 2. Results revealed that, the tine harrow operation requires the range of 6.5 – 7.5 lha⁻¹ of fuel for tilling depth between 10 – 30 cm operated under speed range from 6 – 8km/hr and cutting width varying from 60 – 180 cm.

Table 2: 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

Run order	Coded factors			Actual factors			Energy Requirements	
	A	B	C	Harrowing depth (cm)	Effective working Width (cm)	Operational speed (km/hr)	Actual values of fuel consumption rate l/ha	Predicted values of fuel consumption rate l/ha
1	-1	0	-1	5	60	7	7.0	7.48
2	1	1	0	10	180	7	7.0	7.35
3	-1	1	0	10	60	7	7.0	7.65
4	0	-	1	5	120	6	6.5	7.28
5	0	1	0	5	120	6	6.5	6.96
6	0	0	0	10	120	6	7.0	7.85
7	0	0	1	8	120	7	7.0	7.29
8	1	1	0	10	180	6	7.5	7.85
9	0	1	0	8	120	8	7.0	7.49
10	1	0	-1	5	180	8	7.5	7.50
11	0	0	-1	8	120	8	6.5	7.28
12	1	-	1	10	180	6	7.0	7.63
13	0	1	-1	10	120	6	7.0	7.49
14	-1	0	0	8	60	6	7.0	7.64
15	-1	1	1	8	60	7	7.0	7.83
16	0	-	0	8	120	6	7.0	7.49
17	0	1	0	5	120	7	7.0	7.53
	0							
	0							
	0							

Figure 1 shows the response surface diagram of operational speeds, working width and cutting depth against the fuel consumption rate showing the relationship among the factors (operational speed, width and harrowing depth) and the response (fuel consumption rate). The result shows that the fuel consumption rate increases with tillage depth and that the resultant impact of increasing the tillage as from 30cm depth on fuel consumption rate is higher than the resultant impact observed in increasing the operational speed.

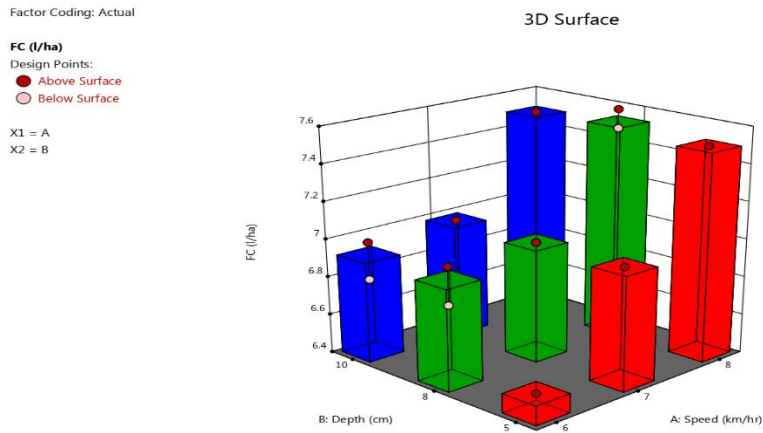


Fig. 1. Response Surface Plot of Tillage Depth of the Tine Harrow and Operational Speed against Fuel Consumption

Table 3: ANOVA for selected factorial model for fuel consumption rate

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	2.86	8	0.3575	107.25	< 0.0001 significant
A-Speed	2.48	2	1.24	372.33	< 0.0001
B-Depth	0.1356	2	0.0678	20.33	< 0.0001
AB	0.2422	4	0.0606	18.17	< 0.0001
Pure Error	0.0600	18	0.0033		
Cor Total	2.92	26			

Table 3 presents the ANOVA for selected factorial model for fuel consumption rate. The Model F-value of 107.25 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, AB are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 4: Fit Statistics for fuel consumption rate

Std. Dev.	0.0577	R ²	0.9795
Mean	7.10	Adjusted R ²	0.9703
C.V. %	0.8132	Predicted R ²	0.9538
		Adequacy Precision	31.0000

Table 4 show the Fit Statistics for fuel consumption rate. The Predicted R² of 0.9538 is in reasonable agreement with the Adjusted R² of 0.9703; i.e. the difference is less than 0.2.

Adequacy Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 31.000 indicates an adequate signal. This model can be used to navigate the design space.

3.2 Model assessment of energy requirements (fuel consumption rate) of tine harrow

The energy requirement of the disc harrow in clay-loam soil is dependent on the results displaying significant difference of the factors (tillage parameters). The contributions, effects, coefficient of model terms, lack of-fit test and significance of the factors and their interactions on the fuel consumption rate were examined according to Fakayode et al. (2016) and Umani et al. (2019). From the statistical analysis conducted, a quadratic model equation was suggested for the evaluation of fuel consumption of the disc harrow as displayed in Table 5. The developed model though existed insignificant as recorded in Table 6 for the response ($P > 0.05$) implies that the model term could not be noted at 95 % level of significant. The model developed to estimate the energy requirement (fuel consumption rate) with respect to the independent variables or functional operating parameters (operational speed, effective working width and cutting depth) is as expressed in Equation 4.

$$FC = 5.0D + 7.0S + 10.0D + 7.0S + 10.0D + 6.0S + 5.0D + 6.0S + 5.0D + 6.0S + 10.0D + 7.0S + 8.0D + 6.0S + 10.0D + 8.0S + 8.0D + 8.0S + 5.0D + 8.0S + 8.0D + 6.0D + 8.0S + 6.0D + 10.0S + 7.0D + 8.0S + 8.0D + 7.0S \quad (4)$$

Where: FC = fuel consumption rate, l/ha; D = harrowing depth, cm; S = operational speed, km/hr

The p-value of the model term is 0.1479 (Table 6) which is above α - level of 0.05 and suggests that the model is insignificant, in other words, the functional or operating parameters have insignificant effects on the fuel consumption rate of the implement except the depth of cut in which the p-value is 0.0347 which is lower than the chosen α - level of 0.05. Thus, depth of cut has major influence on the fuel intake/consumption rate of disc plough as compared to the operational speed and working width of the machine. This is consistence with the findings of Kareem and Sven (2019) and Ajav and Adewoyin (2012). P-values less than 0.0500 indicate model terms are significant. In this case A, C² are significant model terms. The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

Table 5: ANOVA of model summery statistics tine harrow

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	833.00	1	833.00			
Linear vs Mean	0.5625	3	0.1875	1.70	0.2169	
2FI vs Linear	0.3125	3	0.1042	0.9259	0.4634	
Quadratic vs 2FI	0.6125	3	0.2042	2.79	0.1192	Suggested
Cubic vs Quadratic	0.3125	3	0.1042	2.08	0.2451	Aliased
Residual	0.2000	4	0.0500			
Total	835.00	17	49.12			

Table 6: ANOVA of response surface model for fuel consumption rate.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1.49	9	0.1653	2.26	0.1479 not significant
A-Tillage Depth	0.5000	1	0.5000	6.83	0.0347
B-Width	0.0312	1	0.0312	0.4268	0.5344
C-Speed	0.0313	1	0.0313	0.4268	0.5344
AB	0.2500	1	0.2500	3.41	0.1071
AC	0.0000	1	0.0000	0.0000	1.0000
BC	0.0625	1	0.0625	0.8537	0.3863
A ²	0.0007	1	0.0007	0.0090	0.9271
B ²	0.0796	1	0.0796	1.09	0.3317
C ²	0.5533	1	0.5533	7.56	0.0285
Residual	0.5125	7	0.0732		
Lack of Fit	0.3125	3	0.1042	2.08	0.2451 not significant
Pure Error	0.2000	4	0.0500		
Cor Total	2.00	16			

3.2 Model validation of Energy requirements of the harrow

The results of the validation of the developed model equation for energy requirements are presented in Table 6. The results revealed that the model is significant with coefficient of determination, R² of 0.6238, which shows good relationships among the independent variables. It is an indication that the response model (fuel consumption rate) could describe 62.38% of the overall changeability in the response. The simulation of the model equation obtained indicated that the fuel consumption rate (energy requirements) is in the trial array. A negative Predicted R² of -1.7663 implies that the overall mean may be a better predictor of the response than the current model according to Kothari (2014). Adequacy Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 6.0455 indicates an adequate signal. This model can be used to navigate the design space.

Table 6 Model Summary Statistics/validation of model term

Std. Dev.	0.2706 R ²	0.6238
Mean	7.00 Adjusted R ²	0.5143
C.V. %	3.87 Predicted R ²	-1.7663
	Adeq Precision	6.0455

3.3 Optimization of the energy requirements of tine harrow

The optimization of the functional parameter; operating speed, working width and tillage depth of tine harrow on clay-loam soil was conducted using Response Surface Methodology (RSM) in order to minimize the fuel consumption rate (energy requirement). Fig 2 shows the curve of the optimization process with the optimal operating factor of operational speed of 6.15 km/hr, working width of 180cm and tillage depth of 30cm. The optimum fuel consumption rate and the desirability of 7.17 l/ha and 0.697 were respectively obtained. The optimum depth as shown by the result of optimization is in line with the specification of Adewoyin and Ajav (2013).

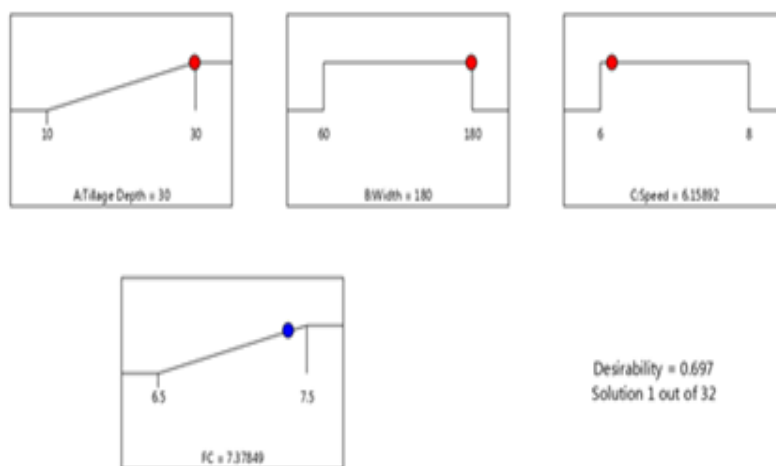


Figure 2 Optimization curve of the fuel consumption rate of a Tine Harrow

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 fuel consumption rate of a tine harrow on clay loam soil in Abia state, under field conditions in South-East agro-ecological region of Nigeria for suitable selection, operation and matching of the implement. 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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