Assessment and Modeling of Drawbar Power Necessities of Disc Plough in Sandy-clay Soil in South-East Nigeria

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Abstract:
The incongruities between agro-ecological soil states demand statistical records of the performance of tillage equipment under various soil classifications for proper choice of implements to minimize charge, curtail energy wastage, and upsurge agricultural output. This research was carried out to assess and model the drawbar power requirements of disc plough on sandy-clay soil in South – East Nigeria that will help farmers predict the power requirements and detect the optimum value of power demand of the plough in orderto select apposite plough subject to the soil type for proficient and bravura productions. Results showed that the highest drawbar power of 5.42kW was achieved when the plough was engaged at full working width of 180 cm, at tillage depth of 15 cm and least operational speed of 6km/hr. The statistical analyses revealed that tillage depth and operational speed have a significant effect ($p< 0.05$) on the drawbar power of the disc plough compared to the effective working width of the plough.The quadratic model was statistically significant for the response ($P < 0.05$). Results also pointed out that the coefficient of determination; R2 was 0.9759 for drawbar power, which indicated high correlations amid the factors. The adequacy Precision of 19.912 obtained indicated decorous indicator and that the models could navigate the design space. The optimum drawbar power of 4.95kW was achieved with the desirability of 1.000 at optimal effective working width of 119.06 cm, ploughing depth of 13.71 cm and operational speed of 7.74kmh-1. Farmers can henceforth, appraise and select the disc plough implements with the developed model equation.

Keywords: Agriculturists, drawbar power, disc plough, modeling, soil tillage.

1. Introduction

Ploughing is an aspect of soil tillage carefully considered as a major farm operation intended to influence the soil to produce a seemly environment for plant growth and development. It is an exercise premeditated to fashioning a favorite soil environment for seeds from some adversarial original soil state by manipulating the soil with the aim to boosting productivities [20]. Several tillage apparatuses are deployed to formulate seedbed. Upadhyayaet al. [19] noted that the choice of tillage tools for soil preparation and weed control hinged on soil type and condition, type of crop, crop residues and weed type. One of the most widely used tillage implements by farmers in South-east Nigeria isthe disc plough. Olatunji [14] defined soil tillage as the automated pulverization of land intended to improve soil environments for bountiful yield; and added that this characterizes the utmost expensive solitary element on the financial plan of farmers. According to the researcher, tillage offers good weed control with minimum herbicide cost; permits the eradication of crop infestation and pests by eliminating them completely via burying the residues from crops.

The vigorous changes of top soil in response to tillage tools are foremost issue in measuring their enactment [8]. The collaboration among ploughing tools and soil is of a principal attention to designing and utilizing the implements aimed at soil pulverization [3]. Tillage process involves the most power and energy consumed on farms. Thus, draft force and drawbar power necessities are imperative for apposite choice of size of tractor that could be used for a specific implement. Naderloo et al. [23] noted that soil conditions also affect the draft required for a given contrivance. Van Muysenet al. [24] studied the impact of soil situations, ploughing depth of cut and speediness of operation on topsoil cultivation using chisel plough while Arvidsson et al. [21] investigated the specific draft, energy requirement of moldboard plough, chisel plough and disc harrow under different soil conditions. They noticed that the specific draft remained mostly the uppermost by the chisel plough while least was the moldboard plough and harrow. The variations were due to variances among contrivance geometry and manner of soil pulverization. A good measure used to consider the fitness of an implement for tillage operation is the force required in drawing the contrivance to pulverize through the soil [15; 9].

One of the elementary thoughts in choosing farm ploughing equipment is the size. Plough effective cutting width and operational speed are frequently enough records to appositely match the size of the device to the farming enterprise, similarly imperative in the selection is the consideration of the power requirements of the tools in order to match the agriculturalist's power unit. For the reason that the power necessities of tillage equipment are large, the suitability is typically critical. The greatest challenging use of the power unit will be achieved simply once the contrivance is matched appropriately to the tractor's obtainable power. The power requirements of tillage equipment are principally reliant on the operational speed and the tillage depth. Other features that affect the power requirements are soil bulk density, moisture content, texture, superficial trash situations, weed growth, compression and shear strength of the soil [9]. Moitziet al. [10] noted that, the overall draw-bar power needed for land cultivation is reliant largely on effective operational depth. According to Boxberger et al. [4], about 150 t/ha (soil density: 1.5 kg dm-3) ought to be relocated if 1 cm soil is tilled. Moenifar et al. [11] noted that the tillage process requires the most energy and power used on farms. Hence, draft force and draw-bar power necessities are essential for apposite selection of size of tractor which might be used to operate a particular implement. The drawbar power and draft force needed for the operation of any device is reliant on soil environments and the geometry of tillage tool [23; 15].

Study on the assessment and modeling of drawbar power necessities of disc plough is vital and a means of helping farmers in assessing and predicting the credible capabilities of ploughing equipment for suitable selection of the implement in view of the soil environment prior to acquiring and deploying the mechanism for task. This study is aimed at assessing and modeling the drawbar power necessities of disc plough on sandy-clay soil in South – East Nigeria that will help farmers predict the power requirements and detect the optimum value of power demand of the plough in order to select apposite plough subject to the soil type for proficient and bravura productions in the region and other areas with similar soil type/conditions in evaluating and choosing plough implement to reduce charge and lessen energy wastage.

2. Study Materials and Methods

2.*1 Research Site*

The research took place in the research farm of Michael Okpara University of Agriculture, Umudike (05° 25′N/ 7° 34′E), Abia State, Nigeria. The climatic state within the farm is categorized by a mean temperature of 27°C, yearly rainfall varying from 2250 to 2500mmand mean relative humidity of 75%, typical of tropical rain forest areas [2]. Sandy-clay is appropriate for arable farming.

The experimental area has average soil bulk density of 1.68 g/cm^3, porosity of 37.40%, moisture content varying from 12.35% to 18.90% (w.b) and granular in structure.

2.2 *Tractor and plough used*

A Massey Ferguson tractor of model MF430E and capacity measuring 55.2kwwith 3- point hitch device and a disc plough obtained from Works Department, Michael Okpara University of Agriculture was used for the research.

2.3 Field Test process

The tillage task was conducted using disc plow at selected effective working widths of 60, 120 and 180 cm and tillage depths of 10, 15 and 20 cm at selected forward speeds of 6,7 and 8 km/hr. The area worked and the equivalent time taken to till the area was recorded according to Oduma*et al*.[12].

2.5 Determination of Drawbar Power Requirement

Drawbar power is the power transmitted via the drive wheels or tracks to move the tractor and implement. This was assessed using Equation 1 conferring to Rangapara *et al*. [22].

$$\text{Drawbar power (kW)} = \frac{Total\ Draft \times operating\ speed\ (km/hr)}{3.6} \quad (1)$$

2.6 *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 that were varied at three levels of tillage depths which include 10, 15, 20 cm, three effective working widths of 60, 120 and 180cm and three forward speeds (6, 7, and 8 km/hr). Central Composite Response Design that generates 17 test scores was conducted for every trial using Equation 2 [18].

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

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

In order to obtain the desired statistics, the array of figures for each of the three (3) factors (k) was assessed as recorded in Table 1. Working width, speed and tillage depth were espoused as independent factors for the drawbar power requirement of the plough. The response selected was the drawbar power, kW. Four replications of the center points were espoused to calculate a fit and succinct estimate of errors; the research was carried out 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	10	15	20
Operational speed (km/hr)	C	6	7	8

2.7 *Response Surface Methodology (RSM)*

The Design Expert of version 11.0 was employed in designing the research, analyzing the data obtained, optimizing the practical factors and producing 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 implement's draft force and drawbar power; the equation models were fitted to the obtained investigational data.

Data obtained were analyzed using (RSM) to fix the quadratic polynomial equation gotten from the Design Expert Software as stated in Equation (3) follwing Chih *et al.* [5].

$$Y = \beta_0 + \sum_{i=1}^{2} \beta i X i + \sum_{i=1}^{2} \beta i i X i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{2} \beta i j X i X j \quad (3)$$

where: Y = Response; β_0 = constant term; $\sum_{i=1}^{2} \beta i$ = Summation of coefficient of linear terms; $\sum_{i=1}^{2} \beta i i =$ Summation of quadratic terms; $\sum_{i=1}^{2} \sum_{j=i+1}^{2} \beta i j$ = summation of coefficient of interaction terms; $XiXj =$ independent variables.

Similarly, the multiple regressions was espoused to fit the coefficient of the polynomial model to let the response variables be allied 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 response (drawbar power) 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 $\propto$ = 0.05 using Minitab 17.0.

3.0 Results and Discussion

3.1 *Tillage maneuver*

The Tillage process was accomplished at selected ploughing width (60, 120 and 180 cm) with designated speeds (6, 7 and 8 cm) and tillage depths of 10 cm, 15 cm and 20 cm at moisture level varying from12.35% to 18.9% and the results of the drawbar power requirements of the disc plough was shown in Table 2. Results showed that the values of the drawbar power recorded during the ploughing operation ranged from 2.90 – 5.42kW for the range of working width (60 - 180 cm), operational speed (6 - 8 km/hr) and ploughing depth varying from 10 to 20cm. Results revealed that the highest drawbar power of 5.42kW was achieved when the plough was operated at full working width of 180 cm, tillage depth of 15 cm and operational speed of 6km/hr. While the lowest drawbar power of 2.90 kW was recorded at operational speed of 8km/hr, effective working width of 60 cm and ploughing depth of15 cm. The highest drawbar power recorded at least operational speed of the plough corresponds to the observation of Odumaet *al*. [12] in the study of the effect of soil type and working speed on enactment of some designated farm machinery in south east Nigeria, where they noticed that plough had the uppermost field efficiency of 88.11% at least speed of 6 km h^{-1} in clay – loam soil as compared to other tillage implements and they propounded that at lower operational speed, the plough generates greater traction and draft force required in its task to originally breakdown the compressed soil in order to create an enabling environment for the germination and proper growth of crops.

It was broadly noted that at different ploughing width and operational speed, the drawbar power upsurges with the increase in ploughing penetration to the soil (cutting depth) and increased to maximum of 70% at ploughing depth of 15 cm, speed of 6 km/hr and effective working depth of 180 cm. This result is reliable with the view of Ajav and Adewoyin [1] in their study on the effect of depth and speed on tractor energy demand in sandy-loam soil of Oyo State, Nigeria, in which they observed that energy demand increases with tillage depth. Nonetheless, the trivial variance in their results and the present research might be ascribed to the differences in soil situations amid dissimilar agro-ecological regions as indicated by Saeed *et al*. [16].

Figure 1shows the response surface plot of effective working width, speeds and tilling depths against the drawbar power requirement of the disc plough indicating the correlation between the factors and the response. Outcomes of figure 1 indicated that the uppermost drawbar power of 5.42kW was achieved when the plough was engaged at full working width of 180 cm, at tillage depth of 15 cm and least operational speed of 6km/hr. The highest drawbar power attained at lowest operational speed of 6km/hr is in agreement with the observations of Olatunji [14] and was accredited to the high traction and draft strength related to low operational speed enabling the device to pierce reasonably deep, thereby breaking down the resisting force and /or strength of the firmed soil thus producing a suitable ecological condition for root penetrationand development as professed by Sale *et al*. [17].

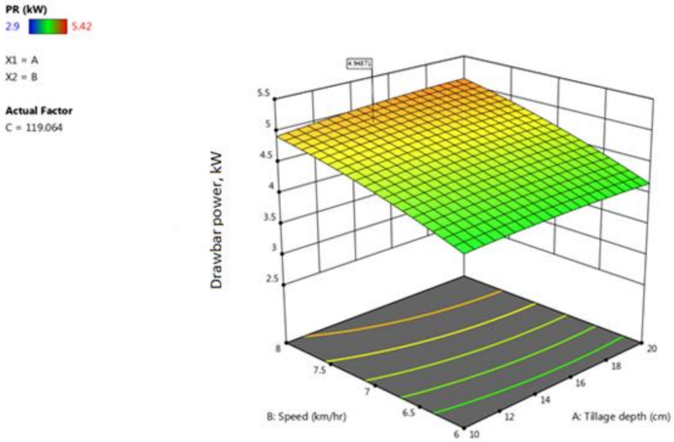

Figure 1 Response surface plot of working width, cutting depth and operational speed against power requirement of the disc ploughin sandy-clay soil.

3.2 *Statistical analysis of results*

The statistical analysis of the impact of ploughing indicators or factors (effective working width, speed and tillage depth) on the drawbar power requirement of the disc plough is presented in the ANOVA results for drawbar power requirement in Table 3. This result indicated that the effect of ploughing depth and operational speed on the drawbar power requirement are significant ($P < 0.05$). This is in tandem with the findings of Kareem and Sven [8]. It therefore implies that the mean drawbar power requirement varies for the different tillage depth and speeds. Inversely, the effect of the effective working width on drawbar power requirement of the plough is insignificant ($P > 0.05$), indicating that the mean drawbar power requirement is not different for the effective working width of the plough.

Table 2 Randomized design layoutof three levels –three factors full factorial composite design of experiment with actual and predicted values of draft force and power requirements of disc plough

Run order	**Coded factors**			**Actual factors**			**Drawbar Power Requirements (kW)**	
	A	B	C	Working Width (m)	Tillage depth (cm)	Operational speed (km/hr)	Actual values of Drawbar Power	Predicted values of Drawbar Power
1	0	0	0	120	15	7	4.71	5.489
2	0	0	0	120	15	7	4.71	5.489
3	0	0	0	120	15	7	4.71	5.489
4	0	0	0	120	15	7	4.71	5.489
5	0	0	0	120	15	7	4.71	5.489
6	1	0	1	180	15	8	5.21	5.299
7	1	0	-1	180	15	6	5.42	5.507
8	-1	0	1	60	15	8	2.90	5.355
9	-1	0	-1	60	15	6	3.79	5.523
10	1	1	0	180	20	7	5.31	5.474
11	1	-1	0	180	10	7	5.20	5.459
12	-1	1	0	60	20	7	3.50	5.453
13	-1	-1	0	60	10	7	3.47	5.443
14	0	1	1	120	20	8	5.31	5.383
15	0	-1	1	120	10	8	5.06	5.376
16	0	1	-1	120	20	6	4.06	5.522
17	0	-1	-1	120	10	6	3.95	5.506

Table 3. Analysis of variance for drawbar power requirement of disc plough

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**
A- Width	0.0312	1	0.0312	0.9744	0.3565
B- Tillage depth	1.50	1	1.50	46.66	0.0002
C-Speed	6.99	1	6.99	218.07	< 0.0001
Pure Error	0.0000	4	0.0000		
Total	9.30	16			

3.3 *Model Equation of drawbar power requirements of disc plough*

The drawbar power requirement of the disc plough in sandy-clay soil is dependent on the results illuminating the significant variation for combination of the operational speed, working width and tillage depth. The model coefficient, effect, contribution, test of lack of-fit and the significance of the factors and their interactions on the drawbar power were evaluated according to Fakayode*et al*. [6] and Umani*et al*. [18]. Both linear and quadratic models were statistically significant for the response ($P < 0.05$) and therefore were suggested (Table 4). This implies that the significant model term was identified at 95% significance level. The quadratic model with the highest order polynomial ($R^2 = 0.9759$) and with significant additional terms as revealed in Table 4 is designated.The quadratic model equation produced to estimate the drawbar power requirement relating to the independent variables (working width, operational speed and tillage depth) is as presented in Equation 4.

$$D_{PR} = 4.71 + 0.063A + 0.433B + 0.935C + 0.035AB + 0.020AC - 0.170BC - 0.038A^2 - 0.078B^2 - 0.303C^2 \quad (6)$$

Where D_{PR} = drawbar power, kW; A = effective working width, cm; B = tillage depth, cm; and C = operational speed, km/hr

The model p-value of 0.0001 recorded in Table 5 is lower than the selected α- level of 0.05 indicating that the model is statistically significant. Therefore, the tillage depth and operational speed except the effective working width with p-value of (0.3565) have significant effects on the drawbar power of the plough. Thus, the model term p-values of 0.0002, 0.0001 and 0.0105 which are less than the selectedα- level of 0.05 stipulate that the model expressions are statistically significant.

As a result, B-tillage depth, C-operational speed andC^2 are significant model terms according to Table 5 which is in proportion to the discoveries of Oduma *et al*. [13] and Ajav and Adewoyin [1].

3.4 *Model validation of the drawbar power requirement of disc plough*

The results of validation of the generated model for the drawbar power of thedisc plough are displayed in Table 6. According to this result, the model is significant with coefficient of determination, $R^2$of 0.9759 and 0.9158 for quadratic and linear models, respectively, suggested.However, the quadratic model with the highest order polynomial (R^2 = 0.9759) and with significant additional terms is selected. The $R^2$of the quadratic model (0.9759) shows remarkable relationships amid theindependent variables and it specifies that the response model can elucidate 97.6% of the entire erraticism in the response. The model equation simulation indicated that the plow's drawbar power requirements fall within the trial range. The Predicted R^2 of 0.6140 was reliable with the Adjusted R^2 of 0.9449 according to Kothari [7].The adjusted R^2 attained is also compatible with the R^2 of 0.9615 obtained by Almaliki*et al.* [3]. The adequacy Precision of 19.912 ratio reached is greater than 4 is suitable to establish an allowable signal and that the model may be espoused to navigate the design space.

Table 4.ANOVA of model summery statistics for drawbar power

Source	Sequential p-value	Lack of Fit p-value	Adjusted R²	Predicted R²	
Linear	**< 0.0001**		**0.8964**	**0.8438**	**Suggested**
2FI	0.6204		0.8863	0.7181	
Quadratic	**0.0455**		**0.9449**	**0.6140**	**Suggested**
Cubic			1.0000		**Aliased**

Table 5: ANOVA of response surface quadratic model for drawbar power requirement

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	9.08	9	1.01	31.46	< 0.0001
A- Width	0.0312	1	0.0312	0.9744	0.3565
B-Tillage depth	1.50	1	1.50	46.66	0.0002
C- speed	6.99	1	6.99	218.07	< 0.0001
AB	0.0049	1	0.0049	0.1528	0.7075
AC	0.0016	1	0.0016	0.0499	0.8296
BC	0.1156	1	0.1156	3.60	0.0994
A²	0.0059	1	0.0059	0.1846	0.6803
B²	0.0253	1	0.0253	0.7885	0.4040
C²	0.3853	1	0.3853	12.01	0.0105
Residual	0.2245	7	0.0321		
Lack of Fit	0.2245	3	0.0748		
Pure Error	0.0000	4	0.0000		
Cor Total	9.30	16			

Table 6.ANOVA of validation of model term for drawbar power

Source	Std. Dev.	R²	Adjusted R²	Predicted R²	PRESS	
Linear	**0.2455**	**0.9158**	**0.8964**	**0.8438**	**1.45**	**Suggested**
2FI	0.2571	0.9289	0.8863	0.7181	2.62	
Quadratic	**0.1791**	**0.9759**	**0.9449**	**0.6140**	**3.59**	**Suggested**
Cubic	0.0000	1.0000	1.0000		*	Aliased

3.5 *Optimization of the drawbar power requirement of disc plough*

Optimizing the drawbar power requirement of disc plough was conducted using a design expert in response surface methodology.Figure 2presents the response plot of the optimization process with the optimumfunctional factors of effective working width of 119.06 cm, operational speed of 7.74kmh^{-1}and ploughing depth of 13.71 cm. Correspondingly, the optimum drawbar power requirementof 4.95Kwwas obtained and the desirability of 1.00 was obtained for the response.The optimum values of speed and depth which gave the optimum value of drawbar power in this study fall within the range of values obtained by Kareem and Sven [8] in the study of effect of ploughing depth, tractor forward speed, and plough types on the fuel consumption and tractor performance. However the slight difference may be ascribed to the variation in ecological soil conditions.

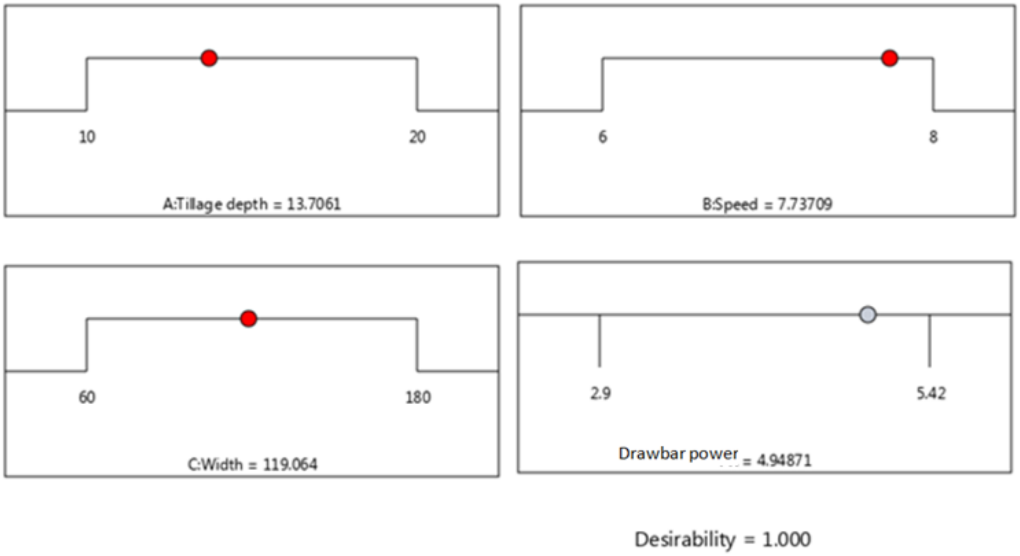

Figure 2 Optimization plot of effective working width, operational speed, tillage depth and drawbar power requirement of disc plough

4. Conclusion

The modeling of the drawbar power requirement of disc ploughon sandy-clay soil in South-East Nigeria was meritoriously carried out. In the course of the ploughingprocess, it was noticed that the highest drawbar power of 5.42kW was achieved when the plough was engaged at full working width of 180 cm, at tillage depth of 15 cm and least operational speed of 6km/hr. The statistical analyses showed that the quadratic model was recommended for predicting the drawbar power requirement of the disc plough.

The developed models and the coefficients were statistically significant. The predicted and adjusted R^2 values were determinedly consistent. Therefore, the trial values were suitable with the coefficient of determination ($R^2 = 0.9759$), proposing excellent correlations amid the independent variables.

Tillage depth and operational speed has significant effect ($p < 0.05$) on drawbar power of the disc plough as compared to the effective working width of the plough.

The obtained models will help farmers in evaluating the enactment of the disc plough for proper selection and engagement to work. The optimum drawbar power of 4.95kW was achieved with the desirability of 1.000 at optimal effective working width of 119.06 cm, ploughing depth of 13.71 cm and operational speed of 7.74kmh^{-1}.

5. Recommendations

Disparities emanates in soil situations as well as characteristics between various ecological areas; it is henceforth recommended that further investigations need to be conducted in different regions to obtain records and model equations which can estimate and/or optimize the drawbar power requirement of disc plough task and other tillage implements on diverse soil categories for apposite selection of tools for soil preparation, in order to increase agricultural productivities, minimize expenses, subside energy consumption and unnecessary failures and breakdown during field operations.

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