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MODELING OF TILLAGE OPERATION PARAMETERS FOR DRAFT AND POWER REQUIREMENT FOR THREE TILLAGE IMPLEMENTS IN A LOAMY SOIL

Paul Okoko^{*1}, Emmanuel A. Ajav²

*¹Department of Agricultural and Food Engineering, Faculty of Engineering,
University of Uyo, Uyo, Nigeria*

*²Department of Agricultural and Environmental Engineering,
Faculty of Technology, University of Ibadan, Ibadan, Nigeria*

Abstract: Tillage is the basic operation in agriculture and its energy requirements represent a considerable portion of the energy utilized in crop production. The trials were achieved using five tractor speeds (3.6, 5.4, 7.2, 9.0 and 10.8 km/hr) and five tillage depths (10, 15, 20, 25 and 30 cm) to determine implement speed at different tillage depths for 3-bottom disc plough, spring tine cultivator and offset disc harrow on loamy soil. The design of the experiment used were two factors, five levels factorial of Central Composite Rotatable Design of Response Surface Method. Selected models were analyzed using ANOVA at $\alpha_{0.05}$ and also validated. The high values of the coefficient of determination for all the selected models and the reasonable agreement between the predicted and actual values of draft and power requirement for all the tested implements show that the generated model equations can be used for predictive purposes for draft and power requirement.

Keywords: *Draft, power requirement, tillage, loamy soil, modeling*

^{*} Corresponding Author. E-mail: okokokizito@gmail.com

INTRODUCTION

Agricultural mechanization is considered to be the main factor that contributes to the total energy inputs in agricultural system and tillage and it is an area where massive power is utilized. The three items that are involved in tillage are; the source of power, the soil and the implement, [7].

Studied [2], the influence of speed and depth on the draft of a chisel plough; an offset disc harrow, a mouldboard and a disc plough on sandy, loamy soil in the field. They observed a significant increase in the draft for all the implements with an increase in depth.

The specific drafts of four tillage implements were also affected significantly by speed and depth. Accessed the influence of the geometric factors of flat tillage tools on their draft, cutting efficiency and loosening of moist clay soil [5]. They observed increases in the draft with width, depth, and rake angle of the tools. Estimated the draft and vertical forces [6], soil deformation and normal pressure distribution on four geometrically similar subsoilers using the finite method.

The four subsoilers investigated have a combination of a vertical shank with 15, 23 and 31° included chisels and a 75° rake angle shank with 15° inclined chisels. They reported that a subsoiler with a shank angle of 75° and a chisel angle of 15° had the least draft.

Studied [8], the influence of plough speed on the formation of stress on the Steyr tractor using quarter-bridge strain gauge circuit with temperature compensation. It was discovered that stress on these parts of the three-point linkage system increased when the speed of plough goes up. The values of the average stress acquired were relatively higher when compared with the yield stress of 0.23 kN/m² of the bracket material.

Researched [4], draft and fuel requirements measurement using tractor on-board. It was discovered that the model outputs of the operations for mouldboard plough, chisel plough, field cultivator, row crop planter and grain drill for the draft requirements do not differ significantly from the field data. There was a very close association between the preliminary draft and the predicted draft for the experiment of the implements. The model output of the disc harrow operations for the draft requirement is statistically different from the field data. The model outputs of the implements for the fuel requirements do not differ significantly from the field data.

There was a very close association between the experimental fuel requirement and the predicated fuel requirement for the implements.

Investigated [1], the effect of depth and speed on the fuel consumption of some commonly used farm tractors in selected states of southwestern Nigeria and reported that increase in ploughing depth and ploughing speed increases tractor fuel consumption. Also, fuel consumption varies with different states in southwestern Nigeria due to the variation in the soil and climatic conditions.

They reported further that ploughing depth is the most impactful factor in the determination of tractor fuel consumption during the ploughing operation.

The objectives of this study are to develop model equations using tillage depth and tractor speed as operating parameters and also carryout statistical analysis.

MATERIALS AND METHODS

Study location

The study was conducted at Use Offot located in Uyo Local Government Area of Akwa-Ibom state, Nigeria.

Tractor and tillage implements

The specification of the tractor used in all the field experiments is presented in Table 1. A set of primary and secondary tillage implements comprising of a 3 – bottom disc plough, an offset disc harrow and a spring tine cultivator were used in this research work for evaluating draft and power requirements over a wide range of tractor speeds and tillage depths. These implements are representative of the standard primary, and secondary tillage implements most commonly used for seedbed preparation in Akwa – Ibom State and the study location. They were owned by the Department of Agricultural and Food Engineering, University of Uyo. Implement specifications are given in Table 2.

Table 1. Specifications of tested tractor

Specification	Swaraj tractor, model 978 FE
Effective output (hp)	72(53.7 kW)
Type of Engine	4 – cylinder
Type of Fuel	Diesel
Type of steering system	Power assisted
Type of injector pump	In – line injector
Fuel tank capacity (L)	98
Lifting capacity (kg)	1250
Rated engine speed (rpm)	2200
Type of cooling system	Water – cooled
Country of manufacture	China
Front tyres (size)	6.0 – 16
Inflation pressure (kPa)	360
Rear tyres (size)	14.9 – 28
Inflation pressure (kPa)	180

Table 2. Specifications of implements used during the field test

S/No	Item	Disc Plough	Tine Cultivator	Offset disc harrow
1.	Type (Hitching)	Fully mounted	Fully mounted	Fully mounted
2.	Number of bottoms / discs/ Share blade	3	-	14
3.	Number of tines	-	11	-
4.	Width of tine (cm)	-	6	-
5.	Type of disc blade	Plane concave	-	Plane Concave
6.	Diameter of bottom/disc (cm)	65.3	7	62
7.	Spacing of discs/share blade (cm)	68	10	22.5
8.	Rake angle (°)	35	49	36
9.	Width of implement (cm)	116	66	105
10.	Actual width of cut (cm)	95.1	54.1	91.5
11.	Disc angle (°)	45	-	25
12.	Tilt angle (°)	20	-	15
13.	Weight of implement (kg)	360	266	305

Determination of draft

The draft of all the tillage implements was determined using the equation as given by [3]:

$$D = \frac{W}{Z} + \frac{c \left(\frac{bd}{\sin \beta} \right) + \rho b d v_o^2 \sin \delta / \sin (\delta + \beta)}{Z (\sin \beta + \mu \cos \beta)} \dots \dots \dots (1)$$

Where,

D = Draft of tillage implement, N

W = Weight of soil, N

C = Soil cohesion, kPa

μ = coefficient of internal soil friction

β = angle of the forward failure surface, $^{\circ}$

V_o = speed of operation, m/s

$$Z = \frac{\cos \delta - \mu' \sin \delta}{\sin \delta + \mu' \cos \delta} + \frac{\cos \beta - \mu \sin \beta}{\sin \beta + \mu \cos \beta} \dots \dots \dots (2)$$

μ' = coefficient of internal soil – metal friction

Determination of power requirement

The equation below was used for the determination of the power requirement.

$$P = D V_o \dots \dots \dots (3)$$

Where,

P = power requirement, kW

Experimental Design

The effects of tillage depth and tractor speed on draft and power requirements were examined. The two independent variables considered are very vital parameters affecting draft and power requirements. The design of the experiment used was two factors, five levels, factorial central composite rotatable design (CCRD) of response surface methodology.

For each independent variable, the levels were chosen based on past reports by different researchers on tillage operations using various implements since there is no knowledge on optimization of these parameters on draft and power requirements. Five levels of tillage depths (10, 15, 20, 25 and 30 cm) and tractor speeds (3.6, 5.4, 7.2, 9.0 and 10.8 km/h) were chosen.

An experimental plot of 100 m long by 50 m wide was used for each implement. A plot of 50 m by 50 m (Figure 3.7) was used as a practice area before the beginning of the experimental runs to enable the tractor and the implement to reach the selected tractor speed and tillage depth. Tillage depth was measured as a vertical distance from the top of the undisturbed soil surface to the implements deepest penetration using a steel measuring tape (Figure 3.8). The different tractor speeds (3.6 – 10.8 km/h) were achieved by selecting appropriate gears and adjusting engine throttle at engine speeds of 1600 – 2000 rpm while the tillage depths of (10- 30 cm) were achieved by using tractor depth controller through its quadrant. Time taken for each implement to travel a distance of 100 m was taken and recorded. The distance was divided by the time taken to obtain the implement travel speed.

Model selection for the Dependent Variables

In selecting a model, the polynomial with the highest order and the additional terms in the polynomial are significant, and the model is not aliased, lack-of-fit is not significant, and the maximization of the "Adjusted R²" and the "predicted R²" were considered. The cubic model is aliased and cannot be selected, and when the coefficient of determination (R²) is maximum, and the value of standard deviation is minimum. A Design Expert (version 11.0.1) software package for the design of experiments was utilized to study and to generate model equations for the dependent variables which are draft and power requirement.

RESULTS AND DISCUSSION

Soil analysis test for the study location

Analysis of soil test was carried out at the study location for the three tillage implements. The results of the analysis test for mechanical properties of the soil is presented in Tables 3.

Table 3. Mechanical properties of the soil at the study location for the tillage implements

Soil Parameter	Values		
	3-Bottom Disc Plough	Spring Tine Cultivator	Off-set Disc Harrow
Soil Composition	%	(%)	(%)
Sand	41	41	41
Silt	35	35	35
Clay	24	24	24
Classification	Loam	Loam	Loam
Average Bulk density	(g/cm ³)	(g/cm ³)	(g/cm ³)
	1.32	1.32	1.32
Average Moisture content	(%)	(%)	(%)
	13.9	16.2	15.0

Experimental test results

The average summary of the experimental results for the two-factor, five levels factorial Central Composite Rotatable Design (CCRD) of the response surface methodology (RSM) for draft and power requirement are presented in Tables 4 and 5.

Table 4. Experimental results for draft using three implements on loamy soil

S/N	Factor 1	Factor 2			
	D_T (cm)	S_T (km/h)	D (kN)-3BDP	D (kN)-STC	D (kN)-ODH
1	10	7.2	1.19	0.12	1.02
2	15	5.4	1.78	0.20	1.53
3	15	9.0		0.22	1.68
4	20	3.6	2.53	0.28	2.16
5	20	7.2	2.69	0.30	2.27
6	20	7.2	2.67	0.30	2.27
7	20	7.2	2.69	0.30	2.28
8	20	7.2	2.69	0.30	2.27
9	20	7.2	2.68	0.30	2.27
10	20	10.8	2.77	0.31	2.34
11	25	5.4	3.46	0.40	3.04
12	25	9.0	3.65	0.42	3.16
13	30	7.2	4.64	0.54	3.97

D_T = Tillage Depth (cm); S_T = Tractor Speed (km/h); D = Draft (kN);
3BDP = 3-Bottom Disc Plough; STC = Spring Tine Cultivator; ODH = Offset Disc Harrow

Table 5. Experimental results for power requirement using three implements on loamy soil

S/N	Factor 1		Factor 2		
	D_T (cm)	S_T (km/h)	PR (kW)-3BDP	PR (kW)-STC	PR (kW)-ODH
1	10	7.2	2.28	0.20	1.88
2	15	5.4	2.24	0.28	2.09
3	15	9.0	3.55	0.47	3.52
4	20	3.6	1.94	0.18	1.49
5	20	7.2	4.19	0.39	3.10
6	20	7.2	3.97	0.38	3.06
7	20	7.2	4.11	0.39	3.14
8	20	7.2	4.16	0.39	3.04
9	20	7.2	4.02	0.38	3.08
10	20	10.8	5.04	0.48	3.81
11	25	5.4	3.52	0.49	4.25
12	25	9.0	5.98	0.73	5.59
13	30	7.2	6.58	0.66	4.92

D_T = Tillage Depth (cm); S_T = Tractor Speed (km/h); PR = Power Requirement (kW);
 3BDP = 3-Bottom Disc Plough; STC = Spring Tine Cultivator; ODH = Offset Disc Harrow

Model selection for the tillage operation using draft as the response at the study location

The comparison of the linear, 2FI, quadratic and cubic models for the draft for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location is presented in Tables 9, 10 and 11 respectively. Considering the model with the maximum R^2 value and the minimum standard deviation (with preference given to R^2), quadratic, quadratic and quadratic models were selected to predict the draft of tillage operation for 3-bottom disc plough, spring tine cultivator and offset disc harrow respectively. The final regression equations for the draft for 3-bottom disc plough, spring tine cultivator and offset disc harrow are given in equations 4, 5 and 6 as:

$$D_{3-BDP} = -0.022 + 0.069D_T + 0.044S_T + 0.0017D_T S_T + 0.0023D_T^2 - 0.0028S_T^2 \quad (R^2 = 0.9995) \quad \dots\dots(4)$$

$$D_{STC} = -0.044 + 0.0086D_T + 0.0099S_T - 2.80 \times 10^{-18}D_T S_T + 0.00030D_T^2 - 0.000037S_T^2 \quad R^2 = 0.9991) \quad \dots\dots\dots(5)$$

$$D_{ODH} = -0.19 + 0.064D_T + 0.068S_T - 0.00083D_T S_T + 0.0023D_T^2 - 0.0015S_T^2 \quad (R^2 = 0.9994) \quad \dots\dots\dots(6)$$

Where;

D_{3-BDP} = Draft for 3-bottom disc plough, kN

D_{STC} = Draft for spring tine cultivator, kN

D_{ODH} = Draft for offset disc harrow, kN

D_T = Tillage Depth, cm

S_T = Tractor Speed, km/h

Table 6. Model comparison for the draft for 3-bottom disc plough at the study location

Models	Linear	2FI	Quadratic	Cubic
Std. Dev.	0.0982	0.1030	0.0256	0.0260
R ²	0.9893	0.9894	0.9995	0.9996
Mean	2.72	2.72	2.72	2.72
Adjusted R ²	0.9872	0.9859	0.9991	0.9991
C.V.	3.61	3.79	0.9413	0.9547
Predicted R ²	0.9709	0.9706	0.9963	0.9607
PRESS	0.2624	0.2657	0.0336	0.3549
Adequate precision	72.95	60.23	197.82	169.41

Table 7. Model comparison for the draft for spring tine cultivator at the study location

Models	Linear	2FI	Quadratic	Cubic
Std. Dev.	0.0131	0.0138	0.0042	0.0028
R ²	0.9869	0.9869	0.9991	0.9997
Mean	0.3069	0.3069	0.3069	0.3069
Adjusted R ²	0.9843	0.9825	0.9984	0.9993
C.V.	4.26	4.49	1.36	0.9075
Predicted R ²	0.9663	0.9648	0.9915	0.9655
PRESS	0.0044	0.0046	0.0011	0.0045
Adequate precision	65.79	54.05	145.66	192.21

Table 8. Model comparison for the draft for offset disc harrow at the study location

Models	Linear	2FI	Quadratic	Cubic
Std. Dev.	0.0938	0.0987	0.0246	0.0228
R ²	0.9869	0.9869	0.9994	0.9996
Mean	2.33	2.33	2.33	2.33
Adjusted R ²	0.9843	0.9826	0.9989	0.9991
C.V.	4.03	4.24	1.05	0.9805
Predicted R ²	0.9669	0.9658	0.9950	0.9562
PRESS	0.2221	0.2293	0.0338	0.2934
Adequate precision	65.78	54.11	177.63	164.77

FI = Factorial Interaction; Std. Dev. = Standard deviation; C.V. = Coefficient of Variation; PRESS = Predicted Sum of Square.

The ANOVA for the selected models for the draft for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location is presented in Tables 9, 10 and 11 respectively.

For 3-bottom disc plough, the probability value of 0.0001 (Table 9) of the model is less than the selected α -level of 0.05. This implies that the selected model is significant. The probability values of 0.0001, 0.0001 and 0.0001 (Table 9) of the model expressions are less than the selected α -level of 0.05. This indicates that the model terms are significant. In view of this, D_T , S_T and D_T^2 are significant model expressions.

This denotes that the tillage depth and tractor speed have significant influence on the draft for 3-bottom disc plough at the study location with tillage depth having the more significant influence on the draft force. It was pointed out that the model was significant with an adequate coefficient of determination ($R^2 = 0.9995$).

The high coefficient of determination implies that there is an excellent correlation among the tillage depth and tractor speed.

This value shows that the model for the draft for 3-bottom disc plough at the study location can explain 99.95 % of the total variability in the responses.

For spring tine cultivator, the probability value of 0.0001 (Table 10) of the model is smaller than the selected α -level of 0.05. This specifies that the selected model is significant. The probability values of 0.0001, 0.0002 and 0.0001 (Table 10) of the model expressions are less than the selected α -level of 0.05. This indicates model expressions are significant. In line with this, D_T , S_T and D_T^2 are the significant terms. This shows that the tillage depth and tractor speed all have a significant influence on the draft for 3-bottom disc plough at the study location with tillage depth having the more significant influence on the draft. It was also seen that the model was significant with the coefficient of determination ($R^2 = 0.9991$), implying excellent correlations between the tillage depth and tractor speed. This value designates that the response model (draft) for spring tine cultivator at the study location can describe 99.91 % of the variability of the responses.

For offset disc harrow, the probability value of 0.0001 (Table 11) of the model is less than the selected α -level of 0.05. This specifies that the selected model is significant. The probability values of 0.0001, 0.0001 and 0.0001 (Table 11) of the model expressions are smaller than the selected α -level of 0.05. This shows that the model expression is significant. In view of this, D_T , S_T and D_T^2 are the significant terms. This denotes that the tillage depth and tractor speed all have a significant effect on the draft for 3-bottom disc plough at the study location with tillage depth having the greater influence on the draft. It was pointed out that the model was significant with the coefficient of determination ($R^2 = 0.9994$). This value specifies that the model for the draft for offset disc harrow at the study location can explain 99.94 % of the variability of the responses.

Table 9. Analysis of Variance for response surface quadratic model for the draft for 3-bottom disc plough at the study location

Source of Variation	Sum of Squares	Df	Mean Square	F-Value	p-value
Model	9.02	5	1.80	2753.39	< 0.0001
D_T	8.88	1	8.88	13545.51	< 0.0001
S_T	0.0533	1	0.0533	81.40	< 0.0001
$D_T \times S_T$	0.0009	1	0.0009	1.37	0.2795
D_T^2	0.0749	1	0.0749	114.33	< 0.0001
S_T^2	0.0019	1	0.0019	2.88	0.1336
Residual	0.0046	7	0.0007		
Lack of Fit	0.0043	3	0.0014	17.78	0.0089
Pure Error	0.0003	4	0.0001		
Cor Total	9.02	12			

Table 10. Analysis of Variance for response surface quadratic model for the draft for Spring tine cultivator at the study location

Source of Variation	Sum of squares	Df	Mean Square	F-Value	p-value
Model	0.1306	5	0.0261	1496.62	< 0.0001
D _T	0.1281	1	0.1281	7344.30	< 0.0001
S _T	0.0008	1	0.0008	47.76	0.0002
D _T x S _T	0.0000	1	0.0000	0.0000	1.0000
D _T ²	0.0013	1	0.0013	75.16	< 0.0001
S _T ²	0.0000	1	0.0000	1.85	0.2165
Residual	0.0001	7	0.0000		
Lack of Fit	0.0001	3	0.0000		
Pure Error	0.0000	4	0.0000		
Cor Total	0.1307	12			

Table 11. Analysis of Variance for response surface quadratic model for draft for offset Disc harrow at the study location

Source of Variation	Sum of squares	Df	Mean Square	F-Value	p-value
Model	6.70	5	1.34	2223.17	< 0.0001
D _T	6.59	1	6.59	10922.13	< 0.0001
S _T	0.0331	1	0.0331	54.85	0.0001
D _T x S _T	0.0002	1	0.0002	0.3731	0.5606
D _T ²	0.0726	1	0.0726	120.32	< 0.0001
S _T ²	0.0006	1	0.0006	0.9418	0.3641
Residual	0.0042	7	0.0006		
Lack of Fit	0.0041	3	0.0014	69.02	0.0007
Pure Error	0.0001	4	0.0000		
Cor Total	6.71	12			

^aSignificance; D_T represents tillage depth (cm); S_T represents tractor speed (km/h)

Model selection for the tillage operation using power requirement as the response at the study location

The comparison of the linear, 2FI, quadratic and cubic models for power requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location is presented in Tables 12, 13 and 14 respectively. Considering the model with the maximum R² value and the minimum standard deviation (with preference given to R²), quadratic, linear and linear models were selected to predict the power requirement of tillage operation for 3-bottom disc plough, spring tine cultivator and offset disc harrow respectively. The final regression equations for power requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow are given in equations 4.31, 4.32 and 4.33 as:

$$PR_{3-BDP} = 0.056 - 0.16D_T + 0.50S_T + 0.032D_T S_T + 0.0033D_T^2 - 0.047S_T^2 \quad (R^2 = 0.9875) \dots (7)$$

$$PR_{STC} = -0.39 + 0.023D_T + 0.048S_T \quad (R^2 = 0.8424) \dots (8)$$

$$PR_{ODH} = -2.60 + 0.17D_T + 0.34S_T \quad (R^2 = 0.8357) \dots (9)$$

Where:

PR_{3-BDP} = Power Requirement for 3-bottom disc plough, *kW*

PR_{STC} = Power Requirement for spring tine cultivator, *kW*

PR_{ODH} = Power Requirement for offset disc harrow, *kW*

D_T = Tillage Depth, *cm*

S_T = Tractor Speed, *km/h*

Table 12. Model comparison for power requirement for 3-bottom disc plough at the study location

Models	Linear	2FI	Quadratic	Cubic
Std. Dev.	0.3926	0.3667	0.2002	0.1719
R ²	0.9314	0.9461	0.9875	0.9934
Mean	3.97	3.97	3.97	3.97
Adjusted R ²	0.9176	0.9281	0.9786	0.9842
C.V.	9.89	9.24	5.05	4.33
Predicted R ²	0.8362	0.8454	0.9032	0.4123
PRESS	3.68	3.47	2.17	13.20
Adequate precision	21.76	20.63	34.21	34.41

Table 13. Model comparison for power requirement for spring tine cultivator at the study location

Models	Linear	2FI	Quadratic	Cubic
Std. Dev.	0.0683	0.0715	0.0717	0.0815
R ²	0.8424	0.8445	0.8783	0.8879
Mean	0.4169	0.4169	0.4169	0.4169
Adjusted R ²	0.8109	0.7927	0.7914	0.7309
C.V.	16.38	17.15	17.21	19.54
Predicted R ²	0.6716	0.4956	0.1405	-11.9822
PRESS	0.0972	0.1494	0.2545	3.84
Adequate precision	14.12	11.68	10.33	7.72

Table 14. Model comparison for power requirement for offset disc harrow at the study location

Models	Linear	2FI	Quadratic	Cubic
Std. Dev.	0.5139	0.5415	0.5447	0.6012
R ²	0.8357	0.8358	0.8708	0.8876
Mean	3.31	3.31	3.31	3.31
Adjusted R ²	0.8028	0.7811	0.7785	0.7302
C.V.	15.55	16.38	16.48	18.19
Predicted R ²	0.6540	0.4639	0.0650	-12.0195
PRESS	5.56	8.62	15.03	209.29
Adequate precision	13.92	11.44	10.01	7.77

Note: FI = Factorial Interaction; Std. Dev. = Standard deviation; C.V. = Coefficient of Variation; PRESS = Predicted Sum of Square.

The ANOVA for the selected models for power requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location is presented in Tables 15, 16, and 17 respectively.

For 3-bottom disc plough, the probability value of 0.0001 (Table 15) of the model is less than the selected α -level of 0.05. This implies that the selected model is significant. The probability values of 0.0001, 0.0001, 0.0239 and 0.0080 (Table D15) of the model terms are less than the selected α -level of 0.05.

This specifies that the model terms are significant. In line with this, D_T , S_T , $D_T \times S_T$, and S_T^2 are significant model terms. This indicates that tillage depth and tractor speed have significant influence on power requirement for 3-bottom disc plough at the study location with tillage depth having the more significant influence on the power requirement. It was established that the model was significant with an acceptable coefficient of determination ($R^2 = 0.9875$). The high coefficient of determination indicates that there is an excellent correlation between the tillage depth and tractor speed. This value shows that the model for power requirement for 3-bottom disc plough at the study location can explain 98.75 % of the total variability in the responses.

For spring tine cultivator, the probability value of 0.0042 (Table 16) of the model is less than the selected α -level of 0.05 and it implies that the chosen model is significant. The probability values of 0.0008 and 0.0043 (Table 16) of the model terms are less than the selected α -level of 0.05. This indicates that the model terms are significant. In view of this, D_T and S_T are the significant model terms. This indicates that the tillage depth and tractor speed have significant influence on power requirement for 3-bottom disc plough at the study location with tillage depth having the more significant influence on the power requirement. It was pointed out that the model was significant with the coefficient of determination ($R^2 = 0.8424$), which implies an excellent correlation between the tillage depth and tractor speed. This value shows that the model for power requirement for spring tine cultivator at the study location can describe 84.24 % of the variability of the responses.

For offset disc harrow, the probability value of 0.0001 (Table 17) of the model is less than the selected α -level of 0.05 and it shows that the selected model is significant. The probability values of 0.0002 and 0.0019 (Table 17) of the model terms are less than the selected α -level of 0.05. This specifies that the model terms are significant. In line with this, D_T and S_T are the significant model terms. This implies that the tillage depth and tractor speed have a significant influence on power requirement for offset disc harrow at the study location with tillage depth having the greater influence on the power requirement. It was also established that the model was significant with the coefficient of determination ($R^2 = 0.8357$). This value shows that the model for power requirement for offset disc harrow at the study location can explain 83.57 % of the variability of the responses.

Table 15. Analysis of Variance for response surface quadratic model for power requirement for 3-bottom disc plough at the study location

Source of Variation	Sum of squares	Df	Mean Square	F-Value	p-value
Model	22.17	5	4.43	110.64	< 0.0001
D _T	12.63	1	12.63	315.08	< 0.0001
S _T	8.28	1	8.28	206.68	< 0.0001
D _T x S _T	0.3306	1	0.3306	8.25	0.0239
D _T ²	0.1522	1	0.1522	3.80	0.0923
S _T ²	0.5398	1	0.5398	13.47	0.0080
Residual	0.2806	7	0.0401		
Lack of Fit	0.2460	3	0.0820	9.48	0.0273
Pure Error	0.0346	4	0.0087		
Cor Total	22.45	12			

Table 16. Analysis of Variance for response surface linear model for power requirement for Spring tine cultivator at the study location

Source of Variation	Sum of squares	Df	Mean Square	F-Value	p-value
Model	0.2494	2	0.1247	26.73	< 0.0001
D _T	0.1610	1	0.1610	34.51	0.0002
S _T	0.0884	1	0.0884	18.95	0.0014
Residual	0.0467	10	0.0047		
Lack of Fit	0.0465	6	0.0078	258.56	< 0.0001
Pure Error	0.0001	4	0.0000		
Cor Total	0.2961	12			

Table 17. Analysis of Variance for response surface linear model for power requirement for Offset disc harrow at the study location

Source of Variation	Sum of squares	Df	Mean Square	F-Value	p-value
Model	13.43	2	6.72	25.43	0.0001
D _T	8.86	1	8.86	33.54	0.0002
D _T	4.58	1	4.58	17.32	0.0019
Residual	2.64	10	0.2641		
Lack of Fit	2.64	6	0.4392	296.77	< 0.0001
Pure Error	0.0059	4	0.0015		
Cor Total	16.07	12			

*Significance; D_T represents tillage depth (cm); S_T represents tractor speed (km/h)

Validation of a model for tillage operations for the draft at the study location

A test run under the obtained optimal tillage operating parameters for draft for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location was carried out in order to evaluate the precision of the quadratic, quadratic and quadratic models for draft for 3-bottom disc plough, spring tine cultivator and offset disc harrow respectively. A reasonable agreement between the observed and predicted values for the draft for 3-bottom disc plough, spring tine cultivator and offset disc harrow was obtained from the parity plot among the predicted and the actual values (Figures 1, 2, and 3). There is a high link ($R^2 = 0.9995$; 0.9991 ; and 0.9994 for 3-bottom disc plough, spring tine cultivator and offset disc harrow respectively) between the projected and experimental values for draft which specified that the expected values and experimental values are in satisfactory agreement which means that the data fixed well with the model and contributed to the reasonable evaluation of response for the tillage operation in the range of tillage operating parameters studied.

Figure 1. Predicted and actual values for draft (kN) for 3-bottom disc plough (3-BDP) at the study location

Figure 2. Predicted and actual values for draft (kN) for Spring tine cultivator (STC) at study location

Figure 3. Predicted and actual values for draft (kN) for Offset disc harrow (ODH) at the study location

Comparing the experimental and predicted results (Table 20, 21 and 22) for the optimum draft for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location. It was observed that the deviations between the experimental and predicted values of the draft were low and ranged between 0.01 to 0.10 for 3-bottom disc plough, 0.01 to 0.10 for spring tine cultivator, and 0.01 to 0.10 for offset disc harrow, respectively.

This indicate that the predicted and the experimental values are in close agreement and the generated model can be used satisfactory to predict the draft (kN) for the tillage operation.

Table 20. Experimental, Predicted, Residual, and Standard residual Values of draft for 3-bottom disc plough (3-BDP) at the study location

S/N	D _T (cm)	S _T (km/hr)	Experimental values	Predicted values	Residual values	Standard Residual
1	10	7.2	1.1900	1.1835	0.0065	0.55
2	15	5.4	1.7800	1.8113	-0.0313	-1.72
3	15	9.0	1.9100	1.9146	-0.0046	-0.25
4	20	3.6	2.5300	2.5052	0.0248	2.12
5	20	7.2	2.6900	2.6748	0.0152	0.65
6	20	7.2	2.6700	2.6748	-0.0048	-0.21
7	20	7.2	2.6900	2.6748	0.0152	0.65
8	20	7.2	2.6900	2.6748	0.0152	0.65
9	20	7.2	2.6800	2.6748	0.0052	0.22
10	20	10.8	2.7700	2.7719	-0.0019	-0.16
11	25	5.4	3.4600	3.5013	-0.0413	-2.27
12	25	9.0	3.6500	3.6646	-0.0146	-0.80
13	30	7.2	4.6400	4.6235	0.0165	1.40

Table 21. Experimental, Predicted, Residual, and Standard residual Values of draft for Spring tine cultivator (STC) at the study location

S/N	D _T (cm)	S _T (km/hr)	Experimental values	Predicted values	Residual values	Standard Residual
1	10	7.2	0.12000	0.12463	-0.00463	-2.42
2	15	5.4	0.20000	0.19575	0.00425	1.43
3	15	9.0	0.22000	0.21241	0.00759	2.55
4	20	3.6	0.28000	0.27963	0.00037	0.20
5	20	7.2	0.30000	0.30103	-0.00103	-0.27
6	20	7.2	0.30000	0.30103	-0.00103	-0.27
7	20	7.2	0.30000	0.30103	-0.00103	-0.27
8	20	7.2	0.30000	0.30103	-0.00103	-0.27
9	20	7.2	0.30000	0.30103	-0.00103	-0.27
10	20	10.8	0.31000	0.31296	-0.00296	-1.55
11	25	5.4	0.40000	0.40241	-0.00241	-0.81
12	25	9.0	0.42000	0.41908	0.00092	0.31
13	30	7.2	0.54000	0.53796	0.00204	1.07

Table 22. Experimental, Predicted, Residual, and Standard residual Values of draft for Offset disc harrow (ODH) at the study location

S/N	D _T (cm)	S _T (km/hr)	Experimental values	Predicted values	Residual values	Standard Residual
1	10	7.2	1.0200	1.0238	-0.0038	-0.33
2	15	5.4	1.5300	1.5308	-0.0008	-0.05
3	15	9.0	1.6800	1.6508	0.0292	1.67
4	20	3.6	2.1600	2.1554	0.0046	0.41
5	20	7.2	2.2700	2.2803	-0.0103	-0.46
6	20	7.2	2.2700	2.2803	-0.0103	-0.46
7	20	7.2	2.2800	2.2803	-0.0003	-0.02
8	20	7.2	2.2700	2.2803	-0.0103	-0.46
9	20	7.2	2.2700	2.2803	-0.0103	-0.46
10	20	10.8	2.3400	2.3654	-0.0254	-2.26
11	25	5.4	3.0400	3.0275	0.0125	0.72
12	25	9.0	3.1600	3.1175	0.0425	2.44
13	30	7.2	3.9700	3.9871	-0.0171	-1.52

Validation of a model for tillage operations for power requirement at the study location

A test run under the obtained optimal tillage operating parameters for power requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location was carried out in order to evaluate the precision of the quadratic, linear and linear models for power requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow respectively. A reasonable agreement between the observed and predicted values for power requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow was found from the parity plot among the predicted and the actual values (Figures 4, 5 and 6).

There is a high connection ($R^2 = 0.9875$; 0.8424 ; and 0.8357 for 3-bottom disc plough, spring tine cultivator and offset disc harrow respectively) among the projected and experimental values for power requirement which indicated that the predicted values and experimental values agreed satisfactorily which shows that the data fixed well with the model and gave a reasonable estimate of response for the tillage operation in the range of tillage operating parameters studied.

Figure 4. Predicted and actual values for power requirement (kW) for 3-bottom disc plough (3-BDP) at the study location

Figure 6. Predicted and actual values for power requirement (kW) for Offset disc harrow (ODH) at the study location

Comparing the experimental and predicted results (Table 23, 24 and 25) for the optimum power requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location. It was observed that the deviations between the experimental and predicted values of the draft were low and ranged between 0.01 to 0.12 for 3-bottom disc plough, 0.01 to 0.08 for spring tine cultivator, and 0.01 to 0.44 for offset disc harrow, respectively. This indicate that the predicted and the experimental values are in close agreement and the generated model can be used satisfactory to predict the power requirement (kW) for the tillage operation.

Table 23. Experimental, Predicted, Residual, and Standard residual Values of power requirement for 3-bottom disc plough (3-BDP) at the study location

S/N	D _T (cm)	S _T (km/hr)	Experimental values	Predicted values	Residual values	Standard Residual
1	10	7.2	2.280	2.309	-0.029	-0.31
2	15	5.4	2.240	2.393	-0.153	-1.07
3	15	9.0	3.550	3.480	0.070	0.49
4	20	3.6	1.940	1.759	0.181	1.98
5	20	7.2	4.190	4.034	0.156	0.86
6	20	7.2	3.970	4.034	-0.064	-0.35
7	20	7.2	4.110	4.034	0.076	0.42
8	20	7.2	4.160	4.034	0.126	0.69
9	20	7.2	4.020	4.034	-0.014	-0.08
10	20	10.8	5.040	5.082	-0.042	-0.46
11	25	5.4	3.520	3.870	-0.350	-2.46
12	25	9.0	5.980	6.106	-0.126	-0.89
13	30	7.2	6.580	6.412	0.168	1.83

Table 24. Experimental, Predicted, Residual, and Standard residual Values of power requirement for spring tine cultivator (STC) at the study location

S/N	D _T (cm)	S _T (km/hr)	Experimental values	Predicted values	Residual values	Standard Residual
1	10	7.2	0.2000	0.2361	-0.0361	-1.10
2	15	5.4	0.2800	0.2278	0.0522	1.02
3	15	9.0	0.4700	0.3745	0.0955	1.87
4	20	3.6	0.1800	0.1961	-0.0161	-0.49
5	20	7.2	0.3900	0.4162	-0.0262	-0.40
6	20	7.2	0.3800	0.4162	-0.0362	-0.55
7	20	7.2	0.3900	0.4162	-0.0262	-0.40
8	20	7.2	0.3900	0.4162	-0.0262	-0.40
9	20	7.2	0.3800	0.4162	-0.0362	-0.55
10	20	10.8	0.4800	0.5394	-0.0594	-1.81
11	25	5.4	0.4900	0.4345	0.0555	1.09
12	25	9.0	0.7300	0.6311	0.0989	1.94
13	30	7.2	0.6600	0.6994	-0.0394	-1.20

Table 25. Experimental, Predicted, Residual, and Standard residual Values of power requirement for offset disc harrow (ODH) at the study location

S/N	D _T (cm)	S _T (km/hr)	Experimental values	Predicted values	Residual values	Standard Residual
1	10	7.2	1.880	1.960	-0.080	-0.32
2	15	5.4	2.090	1.806	0.284	0.73
3	15	9.0	3.520	3.086	0.434	1.12
4	20	3.6	1.490	1.694	-0.204	-0.82
5	20	7.2	3.100	3.307	-0.207	-0.42
6	20	7.2	3.060	3.307	-0.247	-0.50
7	20	7.2	3.140	3.307	-0.167	-0.34
8	20	7.2	3.040	3.307	-0.267	-0.54
9	20	7.2	3.080	3.307	-0.227	-0.46
10	20	10.8	3.810	4.164	-0.354	-1.42
11	25	5.4	4.250	3.569	0.681	1.76
12	25	9.0	5.590	4.759	0.831	2.14
13	30	7.2	4.920	5.397	-0.477	-1.91

CONCLUSION

Model equations were generated with a satisfactory high coefficient of determination (R^2) for the two factors and responses on clay loam soil. The high coefficient of determination of the responses showed excellent correlation between tillage depth and tractor speed which would make the models suitable for predictive purposes on a clay loam type of soil.

The Analysis of Variance (ANOVA) for the selected models for all the implements showed that the models chosen are significant.

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MODELIRANJE OPERATIVNIH PARAMETARA OBRADE ZA PLAN POTREBNE SNAGE ZA TRI RADNA TELA U OBRADI ILOVASTOG ZEMLJIŠTA

Paul Okoko¹, Emmanuel A. Ajav²

¹Department of Agricultural and Food Engineering, Faculty of Engineering,
University of Uyo, Uyo, Nigeria

²Department of Agricultural and Environmental Engineering,
Faculty of Technology, University of Ibadan, Ibadan, Nigeria

Sažetak: Obrada zemljišta oranjem je osnovna operacija u poljoprivredi gde energetske potrebe predstavljaju značajan deo potrošene energije koja se koristi u biljnoj proizvodnji.

Probe su izvedene korišćenjem pet brzina kretanja traktora (3,6; 5,4; 7,20 9,0 i 10,8 km/h) i pet dubina obrade zemljišta (10, 15, 20, 25 i 30 cm) da bi se odredila optimalna brzina kretanja traktora sa različitim priključkom i dubinama obrade zemljišta za: diskosni plug (3 radna tela-diska), kultivator sa opružnim motičicama i teška tanjirača.

Zemljište prema mehaničkom sastavu je pretežno ilovastog mehaničkog sastava. Dizajn eksperimenta ima dva faktora: faktorsku analiza sa pet nivoa, i metodu određene površine (CCRD). Odabrani modeli su analizirani korišćenjem testa ANOVA sa 0,05 i takođe su validirani.

Visoke vrednosti koeficijenta determinacije za sve odabrane modele i određeno slaganje između predviđenih i stvarnih vrednosti dubine rada i potrebne snage traktora za sve testirane priključne mašine, pokazuju da se generisane jednačine modela mogu koristiti u svrhe predviđanja plana potrebne snage vučne mašine (traktora) za određene priključne mašine.

Ključne reči: Plan, potrebna snaga, obrada, glinovito zemljište, modeliranje

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