Journal of Agricultural Engineering and Technology (JAET)
JAET - CIGR Section VI Special Issue:
Innovation & Technologies for Sustainable Agricultural Production & Food Sufficiency
JAET, June, 2019. Vol. 24(2):10-20
Published by the Nigerian Institution of Agricultural Engineers (NIAE).

Print ISSN: 014-2222, Electronic ISSN: 2651-558X
www.jaet.com.ng

DRAFT AND POWER REQUIREMENTS FOR SOME TILLAGE IMPLEMENTS OPERATING IN LOAMY SOIL

P. Okoko[1] and E. A. Ajav[2]
[1]Department of Agricultural and Food Engineering, Faculty of Engineering, University of Uyo, Uyo, Nigeria
[2]Department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan, Ibadan, Nigeria
Corresponding Author: *okokokizito@gmail.com*

ABSTRACT
The availability of draft and power requirements data of tillage implements is an important factor in tractor selection and matching of tillage implement. Previous studies had attributed the lack of relevant data to frequent breakdown of tractors and implements on Nigerian farms. The effects of tillage depths (10, 20 and 30 cm) and tractor forward speeds (3.6, 5.4, 7.2, 9.0 and 10.8 km/hr) on draft and power requirements for three selected tillage implements namely 3-bottom disc plough, spring tine cultivator and offset disc harrow operating in loamy soil were investigated. At a tillage depth of 10 cm, draft and power requirements for 3- bottom disc plough at 0.82 m/s; spring tine cultivator at 0.74 m/s and offset disc harrow at 0.79 m/s implements' speeds were 1.06 kN and 0.87 kW; 0.12 kN and 0.09 kW and 0.92 kN and 0.72 kW. The results showed that draft and power requirements increased with increases in tractor speed at increasing levels of tillage depth. There were no optimum values of speed and depth for which minimum draft and power occurred. The 3- bottom disc plough and spring tine cultivator had the highest and lowest draft and power requirements, respectively in loamy soil. Statistical analysis indicated that tractor speed and tillage depth and their interactions had significant effect on draft and power requirement at probability of 5 % ($P \leq 0.05$).

Key words: Tillage, Power requirement, Soil parameters, Bulk density, Loamy soil, Nigeria

1 INTRODUCTION

Mechanized tillage is a component of agricultural mechanization and agricultural mechanization is the use of mechanical devices or systems to replace human muscle in all forms and at any level of sophistication in agricultural production, processing and storage etc in order to reduce human drudgery, improve timeliness and efficiency of various farm operations, bring more land under cultivation, preserve the quality of agricultural produce, provide better rural living condition and markedly advance the economic growth of the rural sector (Anazodo, 1982; Onwualu et al., 2006).

Studies continue to be conducted to measure draft and power requirements of tillage implements under various soil conditions in the developed nations of the world in Asia, America and Europe. Mathematical models have been developed to predict draft of some tillage tools. American Society of Agricultural Engineers (ASAE), (1990) provided mathematical expressions of draft and power requirements for tillage tools in several soil types. Kydd et al. (1984) developed draft equations for tillage implements and found out that variations in climatic conditions, soil moisture, soil hardness and soil types made it difficult to obtain repeatable draft data. Bowers (1985) developed a computer programme using tillage data to calculate implement power requirements. He concluded that thorough reporting of soil conditions, implement description and draft requirement was necessary to obtain useful results. Boston and Rackham (1981) found no mathematical model that predicts draft of tillage tools accurately.

Upadhyaya et al., (1984) reported that draft requirements of a tillage implement depend on soil type and conditions, manner of tool's movement and tool shape. It is a function of implement width, operating depth and the operating speed at which it is pulled (Upadhyaya et al., (2009).

Harrigan and Rotz (1994) proposed a simple function for a range of soil conditions to model tillage draft under general conditions, where draft per unit width or cross-sectional area of the tilled zone is a function of soil type and the operating speed at which the implement is pilled. It has been reported that the draft force of a tillage implement increases with increasing bulk density (Mouazen and Ramon, 2002). This holds true because the soil strength usually increase with increasing bulk density (Horn, 1993).

2. Materials and Methods

2.1 Site for field Experiment

Experiments were conducted at Use Offot, Uyo Local Government area of Akwa-Ibom state, Nigeria. The soil at the experiment site was loamy. Soil samples were collected during the tillage experiments to determine the soil conditions under which the experiment was conducted. The samples were weighed using a weighing balance and the weight of each sample was recorded. Then the samples were placed in an Oven maintained at 1100C for 48 hrs. The dried soil samples were re-weighed and the weight was again recorded. The moisture contents were calculated on a dry weight basis. (Okoko, 2017).

2.1.1 Tractor and Tillage Implements

A set of primary and secondary tillage implements comprising a 3 – bottom disc plough, and Offset Disc Harrow and a spring tine cultivator were used in this study for evaluating draft and power requirements over a wide range of implement travel speed and tillage depths. These implements were 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 Engineering, University of Uyo. Tractor and implement specifications are given in Tables 2 and 3, respectively

2.1.2 Experimental Layout

The parameters investigated for draft and power requirements determination was speed and tillage depth. An experimental plot of 100 m long by 20 m wide was used for each implement, making 100 m by 40 m for a location. A plot of 30 m long by 10 m wide was used as a practice area prior to the beginning of the experimental runs to enable the tractor and the implement to reach the required depth. The implement travel speeds were changed using the hand throttle after ploughing for 50 m and the tillage depths were fixed using the tractor depth controller. Ploughing time, ploughing depth, implement type and width of implement cut of each implement were measure and recorded in three replications. There were fifteen (15) i.e 3 x 5 runs for each of the three implements given a total of 45 runs i.e in the factorial of 3 x 3 x 5 and replicated three times for each implement resulting in one hundred and thirty five (135) runs. The ploughing depths were measured using a steel measuring tape with the undisturbed surface as a reference (Okoko, 2017).

2.2 Determination of angle of internal friction (soil – soil) and Soil Cohesion

Soil cohesion and soil angles of internal friction (soil – soil) were determine using the direct sheer test method as described by Mamman and Oni (2005) while coefficient of friction (soil on soil) was determined using equation (1) as adopted by Grissor et al., (1994):

$$\mu = \tan\varphi = \frac{F}{N} \quad (1)$$

Where:

μ = coefficient of friction (soil on soil)

F = frictional force tangent to the surface, N

N = normal force (perpendicular to the surface), N

φ = angle of internal friction, deg.

2.3 Determination of shear strength of soil

The strength of the soil in the studied location were determined using an equation given by Gill and Vanden-Berg (1967):

$$S = c + \delta \tan\Phi \quad (2)$$

Where:

S = shear strength of the soil, kPa

c = soil cohesion, kPa

δ = normal stress, kPa

Φ = angle of internal soil friction, deg.

2.4 Weight of soil determination

The weight of soil was calculated from the equation according to Srivastava et al., (2006):

$$W = pbd^* \left(L_0 + \frac{L_1 + L_2}{2}\right) \quad (3)$$

Where:

W = weight of soil, N

ρ = bulk density of soil, kg/m^3

b = width of implement, m

d = tillage depth, m

$$d^* = d\{[\sin(\delta + \beta)]/\sin\beta\}, m \quad (4)$$

Lo = length of implement, m

$$L_1 = d\{[\cos(\delta + \beta)]/\sin\beta\}, m \quad (5)$$

L_2 = d* tan δ, m

δ = rake angle, deg.

$$\beta = \frac{(90 - \Phi)}{2} \text{ deg} \quad (6)$$

Φ = angle of internal friction, degree

2.5 Determination of draft requirements

Draft refers to the force required to pull an implement in the horizontal direction of travel (Tajudeen et al., 2010). Machine selection and sizing require an estimate of draft requirements of the implement. The lack of information about implement performance forces the farmer to rely on past experience for selection of tractors and implements. With the escalation in the size of equipment and speed of many new agricultural implements, the farmer's previous experience may be of little value in selecting new machines. Draft force of all the tillage implements was determined using the equation as given by Srivastava et al., (2006):

$$D = \frac{W}{Z} + \frac{c\left(\frac{bd}{\sin\beta}\right) + \rho b d v_o^2 \sin\delta / \sin(\delta+\beta)}{Z(\sin\beta + \mu\cos\beta)} \quad (7)$$

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, deg
V_o = speed of operation, m/s.

$$Z = \frac{\cos\delta - \mu'\sin\delta}{\sin\delta + \mu'\cos\delta} + \frac{\cos\beta - \mu\sin\beta}{\sin\beta + \mu\cos\beta} \quad (8)$$

μ' = coefficient of internal soil – metal friction

2.6 Determination of power requirement

Most farm tractors are rated power- wise according to the maximum observed power take off (PTO) horse power. Draw bar horse power is the horse power actually available to be transmitted by traction through the tractor draw bar to the implement and this is always less than the PTO due to a combination of power losses through the transmission train, rolling resistance and slippage losses of the tires when operating on a traction surface (John et al., 2016). Power requirement for tractor - powered implements is computed according to equation (9) as given by ASABE (2003).

$$P = \frac{D \times S}{3.6} \quad (9)$$

Where:

P = power requirement, W
D = implement draft, N
S = implement travel speed, m/s

2.7 Data Analysis

Statistical analysis based on randomized complete block design (RCBD) with a factorial treatment design of 3 x 3 x 5 to investigate the interactions between implement forward speed and tillage depth was carried out in Excel Programme. Analysis of Variance (ANOVA) tests were carried out to investigate the interactions between implement forward speed and tillage depth to study their significant effect.

3. Results and Discussion

The result of the soil analysis test carried out at Use Offot (loamy soil) is presented in Table 1, while the specifications of the tractor and implements used are presented in Tables 2 and 3 respectively.

Table 1: Soil Analysis Test on Use Offot 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	Loamy	Loamy	Loamy
Average Bulk density at depth of:	(g/cm^3)	(g/cm^3)	(g/cm^3)
0 – 30 cm	1.32	1.32	1.32
Average Moisture content at depth of:	(%)	(%)	(%)
0 – 30 cm	13.9	16.2	15.0
Penetration resistance at depth of:	(MPa)	(MPa)	(MPa)
10 cm	0.63	0.21	0.15
20 cm	0.94	0.28	0.22
30 cm	1.98	1.33	0.23
Soil cohesion at depth of:	(kPa)	(kPa)	(kPa)
0 – 30 cm	12.67	12.67	12.67
Shear stress at depth of:	(kPa)	(kPa)	(kPa)
0 – 30 cm	18.4	18.4	18.4
Soil strength at depth of:	(kPa)	(kPa)	(kPa)
0 – 30 cm	14.9	14.9	14.9
Soil adhesion at depth of:	(kPa)	(kPa)	(kPa)
0 – 30 cm	0.23	0.34	0.30
Weight of soil at depth of:	(N)	(N)	(N)
10 cm	1226.5	124.9	1123.3
20 cm	2821.4	297.5	2594.9
30 cm	4789.3	517.5	4417.0
Angle of internal soil-soil friction at depth of:	(o)	(o)	(o)
0 – 30 cm	34.4	34.4	34.4
Coefficient of internal soil-soil friction at depth of :			
0 – 30 cm	0.68	0.68	0.68
Angle of soil/implement friction at depth of:	(o)	(o)	(o)
10 cm	21.7	11.5	19.8
20 cm	23.6	13.7	21.3
30 cm	25.3	15.8	23.2
Coefficient of soil/implement friction at depth of:			
10 cm	0.40	0.20	0.36
20 cm	0.44	0.24	0.39
30 cm	0.47	0.28	0.43

Table 2: Specifications of tested Tractor

Specification	Swaraj Tractor (Model 978 FE)
Effective output (hp)	72
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 3: Specifications of Implements used during Field Test

S/N	Item	Disc Plough	Tine Cultivator	Offset Disc Harrow
1	Type	Mounted	Mounted	Mounted
2	Number of bottoms / discs/Share blade	3	14	18
3	Type of disc blade	Plane concave	-	Plane concave
4	Diameter of bottom/ disc (cm)	65.3	7	62
5	Spacing of discs/share Blade (cm)	68	10	22.5
6	Rake angle (deg.)	35	49	36

3.1 Influence of Speed on Draft at different levels of Depth

Figures 1-3 illustrates the effect of tractor forward speed on draft at different levels of tillage depth for 3- bottom disc plough, spring tine cultivator and offset disc harrow operating on loamy soil. From these figures, it was observed that draft increased with increase in forward speed. For all levels of speed, draft increased with increase in tillage depth. For a 3 – bottom disc plough, at a tillage depth of 10 cm, draft increased from 1061.4 to 1322.8 N at implement speeds of 0.82 and 2.58 m/s, respectively. The draft obtained at an implement speed of 0.82 m/s increased from1061.4 to 4454.1 N while at speed of 2.58 m/s, draft increased from 1322.8 to 5305.1 N. For a tillage depth of 30 cm, draft increased from 4454.1 to 5305.1 N at implement speeds of 0.82 and 2.58 m/s respectively. For a spring tine cultivator, at a tillage depth 10 cm, draft increased from 116.5 to 149.2 N at implement speeds of 0.74 and 2.60 m/s, respectively. The draft obtained at implement speed of 0.74 m/s increased from 116.5 to 527.4 N while at speed of 2.60 m/s, draft increased from 149.2 to 634.6 N. For a tillage depth of 30 cm, draft increased from 527.4 to 634.6 N at implement speeds of 0.74 and 2.60 m/s, respectively. For an offset disc harrow, at a tillage depth of 10 cm, draft increased from 917.0 to 1141.5 N at implement speeds of 0.79 and 2.54 m/s respectively. The draft obtained at implement speed of 0.79 m/s increased from 917.0 to 3857.3 N while at speed of 2.54 m/s, draft increased from 1141.5 to 4585.2 N. For a tillage depth of 30 cm, draft increased from 3857.3 to 4585.2 N at implement speeds of 0.79 and 2.54 m/s, respectively.

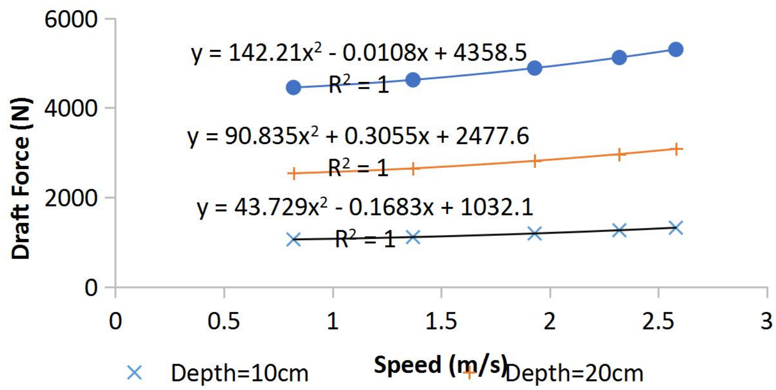

Figure 1: Effect of Speed and Depth on Draft Force for 3-Bottom Disc Plough at Use Offot (loamy soil).

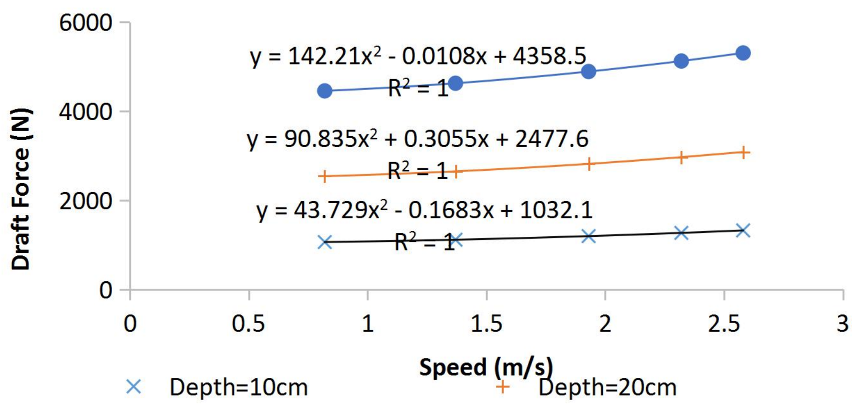

Figure 2: Effect of Speed and Depth on Draft Force for Spring Tine Cultivator at Use Offot (loamy soil).

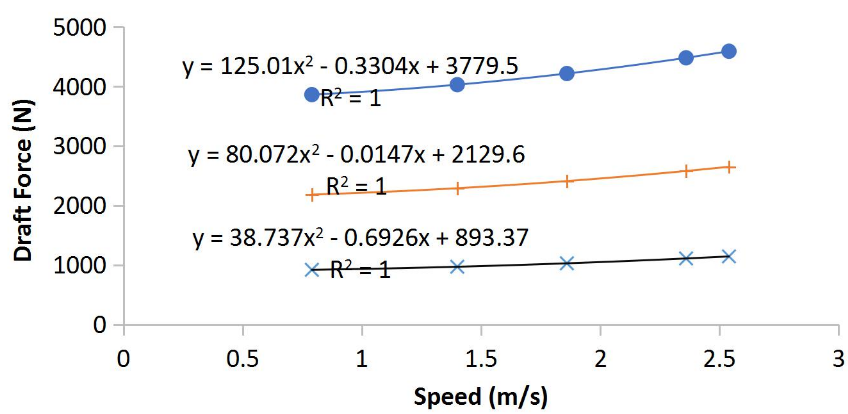

Figure 3: Effect of Speed and Depth on Draft Force for Offset Disc Harrow at Use Offot (Loamy soil).

3.2 Influence of Speed on Power requirements at different levels of Depth

Figures 4 – 6 illustrates the effect of tractor forward speed on power requirement at different levels of tillage depth for 3 – bottom disc plough, spring tine cultivator and offset disc harrow on loamy soil. For a 3 – bottom disc plough, at a tillage depth of 10 cm, power requirement increased from 870.3 to 3412.8 W at implement speeds of 0.82 and 2.58 m/s, respectively. The power requirement obtained at an implement speed of 0.82 m/s increased from 870.3 to 3652.4 W while at speed of 2.58 m/s, power requirement increased from 3412.8 to 13687.2 W. For a tillage depth of 30 cm, power requirement increased from 3652.4 to 13687.2 W at implement speeds of 0.82 and 2.58 m/s, respectively. For a spring tine cultivator, at a tillage depth 10 cm, power requirement increased from 86.2 to 387.9 W at implement speeds of 0.74 and 2.60 m/s, respectively. The power requirement obtained at implement speed of 0.74 m/s increased from 86.2 to 390.3 W while at speed of 2.60 m/s, power requirement increased from 387.9 to 1749.9 W. For a tillage depth of 30 cm, power requirement increased from 390.3 to 1649.9 W at implement speeds of 0.74 and 2.60 m/s, respectively. For an offset disc harrow, at a tillage depth of 10 cm, power requirement increased from 724.4 to 2899.4 W at implement speeds of 0.79 and 2.54 m/s respectively. The power requirement obtained at implement speed of 0.79 m/s increased from 724.4 to 3047.3 W while at speed of 2.54 m/s, power requirement increased from 2899.4 to 11646.4 W. For a tillage depth of 30 cm, power requirement increased from 3047.3 to 11646.4 W at implement speeds of 0.79 and 2.54 m/s, respectively.

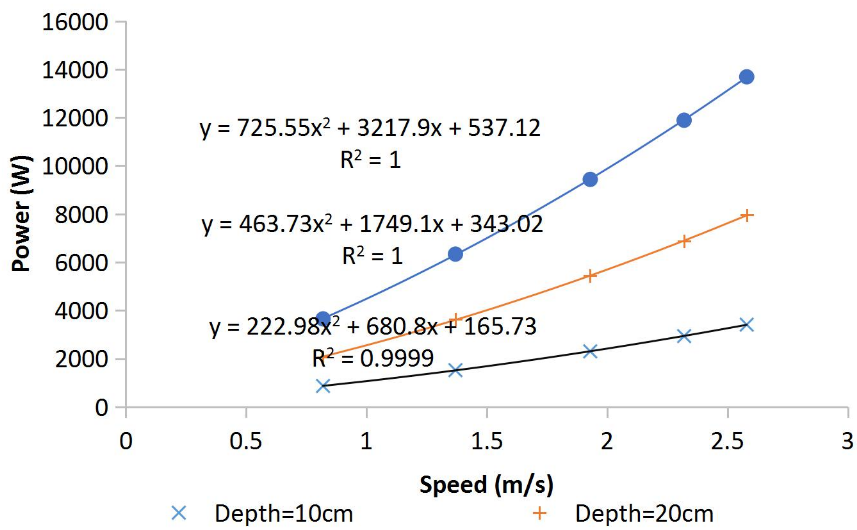

Figure 4: Effect of Speed and Depth on Power Requirement on a Disc Plough at Use Offot (loamy soil)

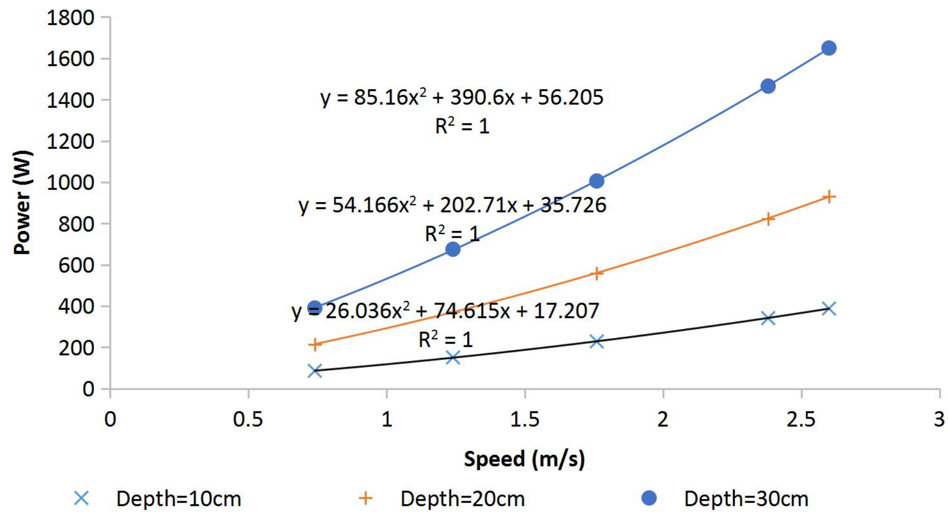

Figure 5: Effect of Speed and Depth on Power Requirement on a Spring Tine Cultivator at Use Offot (loamy soil)

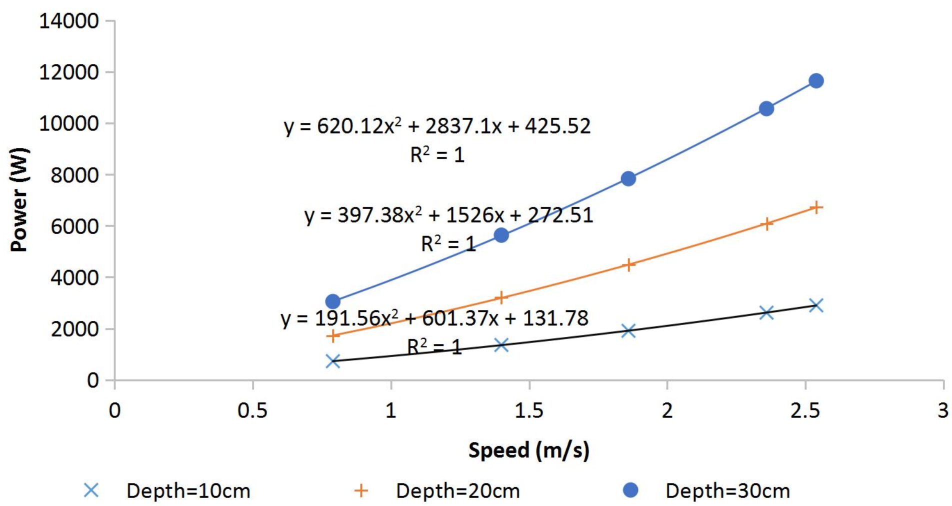

Figure 6: Effect of Speed and Depth on Power Requirement on an Offset Disc Harrow at Use Offot (loamy soil)

3.3 Analysis of Variance for Speed and depth on Draft requirements

The result of the analysis of variance (ANOVA) for the test of speed and tillage depth effect on draft for 3- bottom disc plough, spring tine cultivator and offset disc harrow on loamy soil. The result showed that forward speed and tillage depth affected the draft of the tillage implements significantly at 5% level of probability ($p<0.05$). The interaction between the two factors was also statistically significant at 5% level of probability ($p<0.05$).

3.4 Analysis of Variance for Speed and Depth on Power requirements

The result of the analysis of variance (ANOVA) for the test of speed and tillage depth on power requirement for 3 – bottom disc plough, spring tine cultivator and offset disc harrow on loamy soil. The result indicated that forward speed and tillage depth affected the power requirement of the tillage implements significantly at 5% level of probability (P<0.05). The interaction between the two factors was also statistically significant at 5% level of probability (P<0.05).

4. Conclusion

Field experiments were conducted to examine the effects of implements travel speed depth on the three tillage implements mostly used for seed bed preparation in Use Offot (loamy soil), Uyo Local Government Area of Akwa-Ibom state, Nigeria. A significant increase in draft and power requirements were noticed for all the three tillage implements with an increase in implement travel speed and tillage depth. Analysis of variance (ANOVA) showed that the implement travel speed and tillage depth have significant effect (P≤0.05) on draft and power requirement. In the same way, the interaction between implement travel speed and tillage depth was significant at (P≤0.05).

References

Anazodo, U.G.N. (1982). Mechanization of family farms in Nigeria. Agricultural mechanization in Asia, Africa and Latin America. 8. 3: 59 – 65

ASABE, (1999). Agricultural machinery management data. St Joseph, Michigan, U.S.A.

ASABE, (2003). Current standards for calculating tractor performance parameters including draft. St Joseph, Michigan, U.S.A.

Boston, M.S and Rackham, D.H. (1981). Vibrating soil cutting and improved mathematical models. Journal of agricultural engineering research. 26. 5: 419 – 439.

Bowers. C.G. (1985). South eastern tillage energy data and recommended reporting. Trans. ASAE. 28. 3: 731 – 737.

Gill, W.R. and Vanden-Berg, G.E. (1967). Soil Dynamics in Tillage and Tractor, Agricultural Research service USDA. PP 211- 297.

Grissor, R.D., Yasin, M. and Kocher, M.F.(1994). Tillage implements forces operating in silty clay loam. American society of agricultural and biological engineers.94: 15 - 32.

Harrigan , T.M. and Rotz, C.A. (1994). Draft of major tillage and seeding equipment. ASAE Paper No. 94- 1533. St Joseph, Mich.

Horn, R. (1993). Mechanical properties of structural unsaturated soils. Soil technology. 6: 47 –75.

John, O. A., Jonathan, A. E. and Augustine, A. (2016). Efficient matching of tillage implements with tractors using a computer program. International Journal of agriculture innovations and research (4)6: 2319-1473.

Kydd, H.D., Frehlich, G.E. and Boyden, A.R. (1984). Tillage power requirements in western Canada. American society of agricultural engineers. 84:1027.

Mouazen, A.M. and Ramon, H. (2002). A numerical-statistical hybrid modeling scheme for Evaluation of draught requirements of a sub soiler cutting a sandy loam sol, as affected By moisture content, bulk density and depth. Journal of soil and tillage research. 63:155 – 165.

Mamman, E. and Oni, K.C. (2005). Draught performance of a range of model chisel furrowers. Agric. Eng. Int. CIGR

Okoko, P. (2017). Draft and power requirements of some tillage implements for selected soils in Uyo local Government Area of Akwaa-Ibom State. PhD. Thesis. Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan.

Onwualu, A.P., Akubuo, C.O., and Ahaneku, I.E. (2006). Fundamentals of Engineering for Agriculture. Immaculate Publication Limited ENUGU, Nigeria. ISBN 978-036-133-2.

Srivastava, A.K., Carroll, E.G., Roger, P.R. and Dennis, R.B. (2006). (rev.) Fluid Power, Mechatronics, and Control. Chapter 5 in Engineering Principles of Agricultural Machines, Michigan: 2nd ed., 91-122. St. Joseph, ASABE. Copyright American Society of Agricultural and Biological Engineers.

Tajudeen, A.I., Ayodele, O.O. and Mohammed, S.A. (2010). An object oriented program for matching tractors and implements. International Journal of engineering and technology, (10) 2: 1-6.

Upadhyaya, S.K., Andrade – Sanchez, K., Sakai, K., Chancellor, W.J. and Godwin, R.J. (2009). Advances in soil Dynamics. Vol. 3 Chapter 3, Parts I and II, American Society of Agricultural and Biological Engineers, pp: 273-359.

Upadhyaya, S.K.T.H., Williams, L.J.K and Collins, N.E. (1984). Energy requirements for chiseling in Coastal plain soils. 27. 6: 1643 – 1649