# Draft Requirements for Primary and Secondary Tillage Implements Operating in Loamy Soil

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***Abstract*-Tillage is the basic operation in agriculture and its energy represents a considerable portion of the energy utilized in crop production. In this research, a 72 hp research tractor with three common tillage implements applied to a loamy soil in south- south, Nigeria. Implements included a 3-bottom disc plough, plus spring tine cultivator as primary and offset disc harrow as secondary implements. Operating depths for these implements were 10,20, and 30 cm. Draft requirements determined were compared to those predicted by ASABE standard D497.5 (ASABE Standards, 2006) and were found to vary . It was observed that 3-bottom disc plough has the highest draft requirement followed by offset disc harrow and the spring tine cultivator has the least draft requirement. The difference in implement draft requirement indicates that substantial energy savings can be readily obtained by selecting energy-efficient tillage implements.**

***Keywords:* Draft requirement, tillage implements, Loam soil, plough**

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## I. INTRODUCTION

Agricultural production in the world will be increased many fold in response to an ever growing demand for food by the domestic and world population. Increasing the production while maintaining or reducing the energy inputs will be needed to provide food in the future years to come when energy resources is limited [1].

Crop production systems currently being utilized must be evaluated for energy efficiency and then alternative systems proposed and evaluated [2]. Tillage is the base operation in agricultural systems and its energy represents a considerable portion of the energy utilized in crop production [3]. The availability of draft requirement data of tillage implements is an important factor in selection of machinery, mounting of implements to tractors and estimating fuel consumption for a particular farming situation [4]. Many research studies have been done on measuring energy inputs for tillage implements. Laboratory for soil bin studies are usually done with single tillage tools mounted on an instrumented tool carrier [5]. Most of the research has focused on studying parameters that affect tillage implements draft and on developing draft prediction equations and methods ([4], [6], [7] and [8]). Many of the results of research on tillage implements draft have been summarized in ASABE Standard D497.5 [9]. This standard uses a simplified draft prediction equation proposed by [6]:

$$D = F(A + B \times S + C \times S^2)WT \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where,

D is the implements draft force;

F is a dimensionless soil texture adjustment parameters with different values for fine, medium and coarse textured soils;

A, B and C are machine- specific parameters;

S is field speed; W is implement width; and

T is tillage depth.

The objective of the standard is to provide a draft prediction equation that is applicable to a wide range of soil conditions. The standard provides a good estimate of tillage implement draft but indicates that a range in draft of up to ±50% can be expected within the same broad textural soil class [10]. There are many types of tillage systems such as different combinations of disc plough or other ploughs and field cultivator as primary and disc harrow or other harrows as secondary implements. Draft and energy data for many of these systems are sparse or non-existent. Draft data for a range of conventional primary and secondary tillage implements under local conditions are essential for selecting the most energy- efficient system.

The objectives of this study were to determine draft requirement for three conventional tillage implements applied to a loamy soil and to verify the applicability of the ASABE standard equation for predicting the draft requirements of tillage implements in South- South, Nigeria.

## II. MATERIALS AND METHODS

### *A. Field Site*

The experiment was conducted at Use Offot, Uyo Local Government Area of Akw-Ibom State, Nigeria. The soil at the field site was loamy.

### *B. Pre-Tillage Soil Physical Characterization*

The properties and parameters of soil that have effect on draft requirement include soil moisture content, bulk density, soil cohesion and adhesion, angle of internal friction (soil on soil) and (soil on metal), Shear strength and weight of the soil. Soil samples were collected during the tillage experiment to determine the moisture content. Soil samples were weighed, oven dried at 105$^{o}$C for 24 h and weighed again. Moisture percentages were calculated on a dry basis. [11]. Results of moisture contents and other soil parameters are detailed in Table I.

 

*C. 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 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 Engineering, University of Uyo. Tractor and implement specifications are given in tables 2 and 3, respectively.

*D. Field Experimental Design and Procedure*

The parameters investigated for draft and power requirements determinations were speed and tillage depth. An experimental plot of 100 m long by 20 m wide was used for each implement, making 100m 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 20m 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[11].

*E. 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 [12] while coefficient of friction (soil on soil) was determined using an equation given by [13]:

$$\mu = \tan\varphi = \frac{F}{N} \qquad (2)$$

Where,

$\mu$ = coefficient of friction (soil on soil)
F = frictional force tangent to the surface, N
N = normal force (perpendicular to the surface), N
$\varphi$ = angle of internal friction, deg.

*F. Determination of Shear Strength of Soil.*

The strength of the soil in the studied location was determined using an equation given by [13].

$$S = c + \delta\tan\Phi \qquad (3)$$

Where,

S = shear strength of the soil, kPa
c = soil cohesion, kPa
$\delta$ = normal stess, kPa
$\Phi$ = angle of internal soil friction, deg.

*G. Weight of Soil Determination*

The weight of soil was calculated from the equation according to [14]:

$$W = pbd^{*}\left(L_0 + \frac{L_1 + L_2}{2}\right) \qquad (4)$$

Where,

W = weight of soil, N
$\rho$ = bulk density of soil, kg/m$^3$
b = width of implement, m
d = tillage depth, m
$d^{*} = d\{[\sin(\delta + \beta)]/\sin\beta\}$, m $\qquad (5)$
$L_o$ = length of implement, m
$L_1 = d\{[\cos(\delta + \beta)]/\sin\beta\}$, m $\qquad (6)$
$L_2 = d^{*}\tan\delta$, m
$\delta$ = rake angle, deg.
$\beta = \frac{(90 - \Phi)}{2}$ deg $\qquad (7)$
$\Phi$ = angle of internal friction, degree

*H. Determination of Draft requirements*

Draft force of all the tillage implements was determined using the equation as given by [14].

$$D = \frac{W}{Z} + \frac{C\left(\frac{bd}{\sin\beta}\right) + \rho b d v_0^2 \sin\delta/\sin(\delta+\beta)}{Z(\sin\beta + \mu\cos\beta)} \qquad (8)$$

Where,

D = Draft of tillage implement, N
W =Weight of soil, N
C = Soil cohesion, kPa
$\mu$ = coefficient of internal soil friction
$\beta$ = angle of the forward failure surface, deg
$V_0$ = speed of operation, m/s.

$$Z = \frac{\cos\delta - \mu'\sin\delta}{\sin\delta + \mu'\cos\delta} + \frac{\cos\beta - \mu\sin\beta}{\sin\beta + \mu\cos\beta} \qquad (9)$$

$\mu'$= coefficient of internal soil – metal friction

## III. RESULTS AND DISCUSSION

Table I: 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 – 30cm | 1.32 | 1.32 | 1.32 |

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

## *A. Specification of tested Tractor*

The specification of the tractor used in all the field experiment is presented in Table II.

Table II: 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 |

## *B. Specifications of Implements used for Field Test*

The specifications of the implements used during field test are shown in Table III.

Table III: Specifications of Implements used during Field Test

| S/ No. | 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 |

Results of determined draft requirement of implements are illustrated in Table IV and Figures 1-3. The draft requirement ranged from a minimum of about 368.4 N for the spring tine cultivator to a maximum of 2966.5 N for the disc plough (Table III). This large variation was due to the difference in forward speed and width of the tillage implements. This data could be used by local farmers in the study location for selecting the best combination of tillage implements, size of tractor and tractor implement match. The standard provides coefficients for equation (1). To calculate draft for general classes of tillage implements at a given speed and depth for three broad classes of soil texture, fine, medium and coarse. There was no draft data for disc plough in ASABE Standard, 2006. The ASABE data underestimated the offset disc harrow and spring tine cultivator by 88 % and 48 %. The ASABE coefficients are for a wide range of soil conditions and consequently cannot be expected to yield accurate estimate for a given situation; the ASABE Standard indicates an expected range of ±25 % to ±50 % for the various tillage implements [10]. Except for the spring tine cultivator, where the standards underestimated the determined draft by 48 %, the determined draft was within the expected range of draft given in the ASABE Standard.

Table IV:Draft (N) for Primary and Secondary Tillage Implements used in the study.

| Implements | Obtained Draft (N) | ASABE Estimated Draft (N) |
|---|---|---|
| 3-bottom disc plough | 2966.5 | - |
| Spring tine cultivator | 368.4 | 191.3 |
| Offset disc harrow | 2719.4 | 320.3 |

 

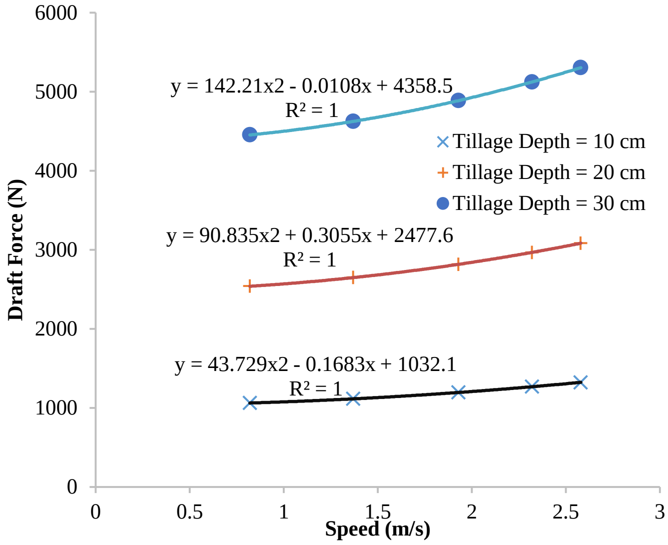

Figure 1: Effect of Speed and Depth on Draft Force for 3-Bottom Disc Plough at Use Offot (Loamy soil).

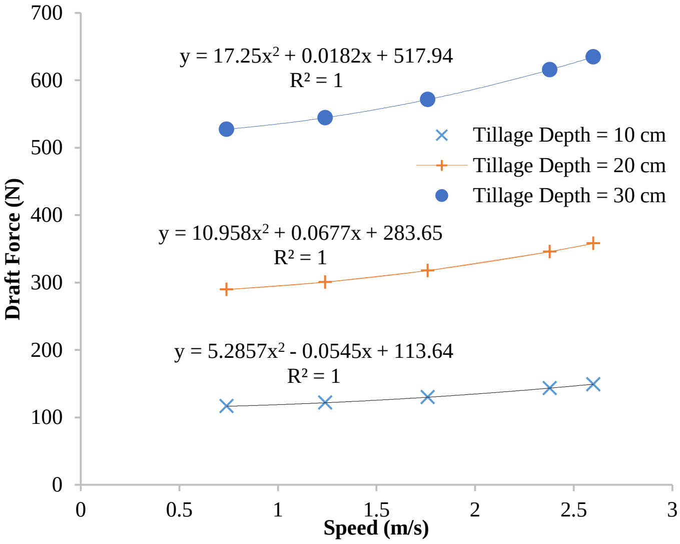

Figure 2: Effect of Speed and Depth on Draft Force for Spring Tine Cultivator at Use Offot (Loamy soil).

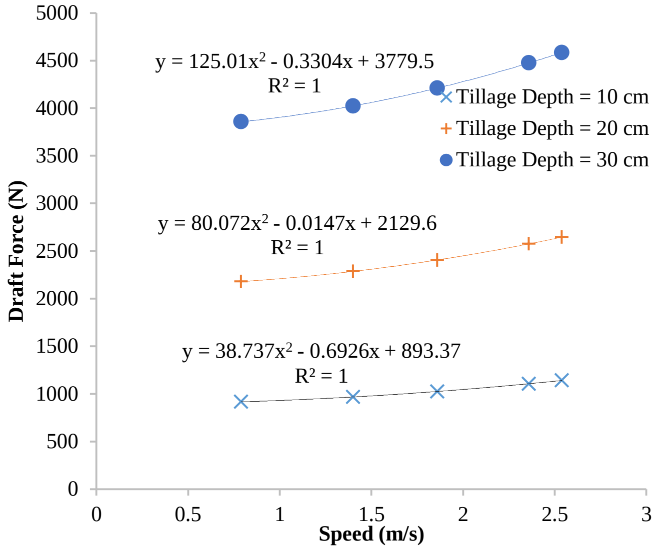

Figure 3: Effect of Speed and Depth on Draft Force for Offset Disc Harrow at Use Offot (Loamy soil).

As the primary purpose of this study was to determine and compare draft for the different implements, we used the implements that were common and available and attempt was not made to optimize the tractor operating parameters or tractor implement match. Many factors influence the size of tractors and tillage equipment acquired on farms and mismatched tractor implement combinations are common. Changing cultural practices, the availability of capital, personal preferences and opinions and the availability of used or new equipment from machinery dealer when the farmer makes a decision to purchase can influence the size of equipment on farms. The range of tractor-implement match for the tillage equipment used in this experiment was considered typical of that found on many farms in Nigeria.

## IV. CONCLUSION

A field experiment was conducted with a view to determine, compare and present the draft requirements for three primary and secondary tillage implements (3-Bottom disc plough, spring tine cultivator and offset disc harrow) in a loamy soil in south- south, Nigeria. The implements were operated at speeds and depths typically used by farmers in the area. Draft requirement obtained were compared to those predicted by ASABE standard D497.5 and were found to vary. Except for the spring tine cultivator, where the standard underestimated the obtained draft by 48 %, the obtained draft was within the expected range of draft given in the ASABE standard. Consequently, was verified the applicability of ASABE standard equation for predicting the draft requirement of tillage implements in south-south, Nigeria. The large difference draft data obtained in this study clearly show that substantial energy savings can be realized by selecting energy-efficient tillage systems. The tillage draft data need to be combined with other agronomic and soils data to select the optimum tillage system for a particular soil and climatic region.

 

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