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A Review on Draught Requirement of Tillage Tools

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Abstract

A review was conducted on the draught force requirement of tillage tools. The draught requirement of different tillage tools on different soils were studied by many researchers. The factors affecting the draught of the implement were studied using different techniques. The effects of operational speed on implement draught were also reviewed. The effects of speed on different tillage and operational parameters were studied by researchers. The effects of tillage parameters on the draught of implement was in the review.

Introduction

The main purpose of soil tillage is to modification the physical characteristics of the soil such as bulk density, soil aggregate, size distribution and other characteristics of soil and also, the elimination of weed, in order to produce soil conditions and environment favourable to crop growth. It is a process to modify soil properties by pulverization, cutting, inversion or movement of the soil resulting in improved soil condition for optimal crop growth and yield, (Grisso *et al.*, 1996).

Draught is the force required to overcome soil resistance and propel an implement in the direction of travel. The tillage implements used in most part of the state are the disc plough and harrow. These implements were imported in different specifications without considering the optimum adjustments required on the implements to produce a quality till, the draught requirement of the implements in relation to the soil conditions among others.

There are many factors that control the performance of tillage implements. These can be divided into three sections: soil, plough and operation factors. Soil variables include: soil moisture content, organic matter, soil bulk density and structure. Plough variables include: plough weight, disc angle and tilt angle, radius of curvature, disc spacing and disc diameter. Operation variables include: forward speed, width and ploughing depth (Panagrahi *et al.,* 1990).

The availability of data on tillage implements parameters is important in selecting suitable tillage implements and making suitable adjustments in specified soils. Farm managers and consultants use data of tillage implements parameter in specific soil types to determine the size of the tractor and type of tillage tool that is required. The study of tillage implements parameter interactive effect variation in tillage operation which relates other tillage parameters such as soil moisture content, tool speed, depth of work, type of tool, etc. provide information for machinery design parameters. It will also improve machinery and implement utilization by reducing the tool draught, proper timing of tillage, improves the quality of work and reduces the cost of tillage. More consequential is in the reduction of soil structure and aggravating the gradual influence of desertification.

The objective of this work is to review the draught requirement of tillage tools

Draught requirement of tillage tools

In an investigation by KarimiInchebron *et al.* (2012) draught, specific draught and drawbar power for moldboard plough were measured in different tillage depths and moisture contents. A randomized complete block design with three replications was used to evaluate the effect of three depths (10, 15 and 20 cm) at three levels of soil moisture content ranges of (16-18%), (19-22%) and (23-25 %db) on draught, specific draught and drawbar power. The result shows that tillage depth and soil moisture content had significant effect of ($P < 0.01$) on the draught and drawbar power. Similarly, the effects of interaction of soil moisture and tillage depth on specific draught were significant at ($P<0.05$). Mean comparison of treatments with Duncan's multiple range test showed that the draught and drawbar power increases as tillage depth increased. It was also found that draught, specific draught and drawbar power requirements decreased significantly with increase in the soil moisture content. In order to increase the draught and drawbar power, the ploughing depth of 20 cm and soil moisture of 23-25% was advised and to increase the specific draught, ploughing depth of 10 cm in every increase of soil moisture content was suggested. The reason for the increase in the tractor draught was because increase in the tillage depth caused an increase in soil failure and bulk density such that more power is required to cut the soil. Similarly, Aykas *et al.* (2004) studied the performance of the heavy-duty offset disc harrow in a soil bin to examine the effect of travel speed, gang angle and weight of the disc harrow on draught and soil conditions. Heavy-duty disc harrow which was reduced to the half its size with 11 discs blades was operated in a soil bin without stubble to see the effect of the tillage parameters alone on the soil conditions. The disc harrow was operated at speeds of 5.2, 7.9 and 9.8 km/h at gang angles of 10, 14 and 22° respectively. The weight, speed and the gang angles were found to be significant on draught, when speed was increased and the interactions of the three factors (weight, speed and gang angles) were also significant at $P \geq 0.05$ and the result of force measurement using load cells indicated a linear relationship with a coefficient of determination of ($R^2 = 0.99$). Draught increased with increase in gang angle, weight and operational speed. The value of draught increased significantly with increase in gang angle of the disc harrow. Increasing the weight of the disc harrow, the clod size also increased at the same gang angle. The weight and the speed did not have any effect on bulk density of the soil.

Furthermore, Askari and Khalifahamzehghasem (2013) conducted a research with 82 kW tractor equipped with an instrumentation system that was used to determine the draught force inputs for four common tillage implements on a clay loam soil. The implements used were mouldboard plough and chisel plough for primary tillage and disc harrow and field cultivator for secondary tillage. The depth of cut for the primary and secondary tillage implements were 250 mm and 100 mm, respectively. Draught of implements were measured and compared to those predicted by American Society of Agricultural and Biological Engineer (ASABE) Standard D497.5 (ASABE, 2006) but were not in agreement with each other. It was found that draught force of mouldboard plough and field cultivator had doubled that of chisel plough and disc harrow. The difference in implement draught indicated that substantial energy can be saved by selecting energy-efficient tillage implements.

The review of research in this section indicated that, draught requirements of different tillage tools has been studied by many researchers on different soils in relation to different moisture content and tillage tool parameters around the world, none of these studies analysed the effect of interaction of tillage tool parameter on the soils of Adamawa state, Nigeria. The need to established data on draught requirement of different implements on the soils of Nigeria has been stressed in the recommendations of (Ani *et al.,* 2007).

Effects of speed on implement draught

Soil engaging tools are drawn by prime movers. This generates straight and stable movement of the implement frame and the tool directly attached to it. The faster the forward speed the more intensive the tool action. In practice however, speed is restricted to 2-3 m\s which is almost 7 km\hr (Koolen and Kuipers, 1983). In most tillage implement, increasing forward speed increases in the value of draught that depends on the type and design of implements and soil conditions. The effect of speed on implement draught depends on the soil type and the type of implement.

Owen (1988) analyzed the effects of implement speed under field conditions in two different compacted soils in relation to the vertical, horizontal and total forces of a sub-soiler tine, force applied to the tine, soil area heaved and disturbed, total soil area, specific resistance and compare the vertical, horizontal and total force to values predicted by a three-dimensional model of the soil wedge failure. Linear regression analysis revealed that, there was a significant effect on the vertical force and had a highly significant quadratic effect on the horizontal force, total force, moment and specific resistance by the tool speed. It also revealed that, soil type has a significant effect on the forces, moment and specific resistance.

Onwualu and Watts (1998) developed regression equations relating the draught and vertical forces for wide (width 25.4 cm, depth 15 cm), narrow (width 5.1 cm, depth 22.9 cm) and plane tillage blades operating in a dystric fluvisol (silty sand texture) in a soil bin. This was to modify the two-dimensional model of Soehne by including the three-dimensional analysis, and to develop a computer program for analysis of soil-tool interaction based on the soehne's model and that of Mckyes and Perumpral. The tools were tested at two depths (10 cm and 15 cm for wide blade, 11.4 cm and 22.9 cm for narrow blade), two rake angles (45^o and 90^o) and eight speed levels (0.25, 0.5, 0.75, 1.00, 1.25, 1.50, 1.75 and 2.00 m/s). The variables were combined in a 2×2×8 factorial experiment with three replications. The performance of three theoretical models based on the trial wedge approach in predicting the experimental results were evaluated.

The soil failure model based on Soehne's approach (Model 1) with modification for the three-dimensional analysis, assumes that the soil fails in a series of shear planes, forming a wedge that is trapezoidal in shape. The equilibrium of the wedge boundary forces produced the force required for failure. The soil failure model based on Mckyes' approach (Model 2) assumes that soil failure is by the formation of a centre wedge flanked by two side crescents. Equilibrium of the boundary forces on the wedge and crescents produce the forces as a function of an unknown failure angle which is obtained by minimizing the weight component of the total force. The soil failure model based on Perumpral's approach (Model 3) assumes the same failure wedge as Model 2 but that the total cutting force is minimized instead. Experimental results show that the tool force (draught and vertical force) was a function of the speed and the square of speed whereas the three models assumed it to be a function of the square of speed only. The models were not very accurate in predicting the experimental results. The average percent deviations of the predicted forces from the observed values were 43%, 40% and 66% for Models 1, 2 and 3, respectively.

Thus, Model 2 result had a more general agreement with the experimental observations. The models were better in predicting the forces (draught and vertical force) for the narrow tool with average percent deviations of 33%, 28% and 46% for

Models 1, 2 and 3, respectively, as compared to 53%, 51% and 85% for the wide blade. Polynomial model of second degree best described the relationship as follows; -

$$D = R_0 + R_1 \nu + R_2 \nu^2 \qquad (1)$$

Where,

D = draught of vertical force (N)

ν = tool speed in (m/s)

R_0, R_1 & R_3 = Regression coefficient

Similarly, Serrano *et al.* (2003) studied the effect of working with disc harrow at a reduced gang angle and at a higher operational speed, in terms of work rate, fuel consumption per hectare and distribution of dry soil aggregate. A medium weight trailing off-set disc harrow was pulled by a four wheeled drive tractor. Draught force, fuel consumption, wheel slip, operational and engine speed were measured using a portable computer-based record system. The study revealed that, the reduction in the draught due to the closure of the angles between the disc gangs prevailed over the increase in the draught due to a higher working speed. It was also found that at higher work rates, lower fuel consumption values were attained, without any physical difference in the soil tilt when the disc harrow was operated at lower gang angles and shift up to the higher gear ratio at constant speed of the engine.

In another study by Ahanekun *et al.* (2003) the effect of tool speed and changes in soil moisture regime on draught and power requirement of a disc plough was investigated, using the trace-tractor technique. Draught and power requirement for disc ploughing increased with speed and soil moisture content for soil moisture levels 3.70% and 5.80% db respectively. However, at soil moisture level 9.20% db draughts and power requirement increased with insignificant value with increase in tool speed. The study further revealed that the optimum speed of operation for disc ploughing is 7km/hr, while the optimum soil moisture content for disc plough lies in the range of 6.0 to 9.0% db for loamy sand soil of Ilorin agro-ecological zone.

Soil strength related properties such as shear strength cone index decreased with increase in soil moisture content and tool speed. At soil moisture levels 5.8 and 9.2% db and implement speed of 7km/hr swell factor obtained were 13.10 and 10.14% respectively. This implied that soil loosening is a function of soil moisture and tool speed. Thus, a linear relationship was established for predicting draught of disc plough under varying soil moisture content and tool speed. A regression analysis carried out to predict draught as a function of tool speed and soil moisture content gave the following equation:

$$D = 0.54 + 0.11Mc + 0.58\,S \quad (R^2 = 0.93) \qquad (2)$$

Where:

D = draught (kN)

Mc = soil moisture content (%) db

S = tool speed (km/hr)

The equation shows a linear increase in draught with increase in both soil moisture and tool speed. The value of coefficient of determination ($R^2 = 0.93$) shows that the fitted equation is satisfactory.

In another investigation, Ahaneku and Ogunjirin (2005) evaluated the effects of the imposition of different levels of tractor forward speed during tillage on some soil physical properties. The speed levels considered were ranging from 1.0 km/h to 10.6 km/h and the depth of cut was constantly maintained at 20 cm throughout the operation. The tillage parameters measured were the cone index, shear strength, bulk density clod mean weight diameter and moisture content. It was found that there was a significant difference in soil physical properties due to the difference in levels of forward speed. Soil strength properties generally decrease with increasing speed this was maintained at constant value of 20 cm. Similarly, Zangiev *et al*. (2007) reported on the following relationship between plough draught and forward speed. By increasing the travel speed the draught increases.

$$D = D_o\, d\,[1 + \Delta D\,(S - S_o)] \tag{3}$$

Where,

D = plough draught, ($kN.m^{-1}$)

D_o = the specific draught of plough, ($kN.m^{-2}$)

d = ploughing depth, (m)

ΔD = constant (rate of change in draught with increase in speed of operation)

S = plough speed, ($m.s^{-1}$)

S_o = primary speed (maximum up to 1.4 ms^{-1})

Serrano and Peca (2008) studied the effects of implement speed on draught required to pull trailed harrow disc and found that draught increases with the increase of forward speed of implements and the relationship is linear between 3 and 9 km/ hr. Also, Al-Suhaibani and Ghali (2013) conducted a field experiment using a fully instrumented data logger tractor to measure the draught of a heavy-duty chisel plough in a sandy soil over wide range of ploughing depth and forward speed, the effects of ploughing depth and forward speed on draught, unit draught, vertical specific draught, horizontal specific draught and coefficient of pulled were analyzed. It was found that, draught, unit draught and vertical specific draught increased with increase in ploughing depth and travel speed. The horizontal draught and coefficient of pull increase with increase in depth but decrease with increase in forward speed. The value of vertical draught was much higher than that of horizontal specific draught for all ploughing depth and speed. Ploughing depth had more effect on draught, unit draught, specific draught and coefficient of pull than travel speed and optimum forward speed was about 1.7 m/s. Nkakini and Fubara-Manuel (2014) used tractor trace technique to investigate the effect of disc ploughing speeds and variations in moisture content on draught. It was found that draught decreased with increase in soil moisture content at constant speed of 1.94, 2.22 and 2.5 m/s respectively. While the optimum moisture content lies between 2.5 to 25 % wb for the soil under consideration. Soil strength properties decreases with increase in moisture content and travel speeds. a linear relationship was established for predicting tractive force of disc plough under varying soil moisture content and forward speed of 1.94, 2.22 and 2.5 m/s as given;

$$Y = -128.1Mc + 15556, \text{ with } R^2 = 0.884\ S_1 \quad (4)$$

$$Y = -127.6Mc + 16582, \text{ with } R^2 = 0.882\ S_2 \quad (5)$$

$$Y = -127.1Mc + 17672, \text{ with } R^2 = 0.883\ S_3 \quad (6)$$

Where,

Y = Tractive force requirement (N)

Mc = soil moisture content (%) wb

The effects of tool speeds on tillage forces were analyzed from nine different studies. In all the studies different types of tillage tools were used on different soils and locations. Four of the studies were conducted with disc plough and in two of the studies, heavy duty disc harrows were examined and subsoiler, chisel plough and plane tillage blade were also examined in the other studies. The results of the studies were in agreement that, for any increase in speed of implement draught increased. Furthermore, three studies were conducted with disc plough on the soils of Nigeria. two investigations were conducted in Ilorin ecological zone and the other one in Umudike. The results reported that, draught increased with speed of implement and soil loosening is a function of speed of tool and moisture content. However, the influences of other parameters of disc plough in relation to draught and speed of implement and the effects of interaction of the parameters were not studied in most part of Nigeria (Nkakini and Fubara-Manuel, 2014).

Effects of tillage parameters on draught

Naderloo *et al*. (2009), tillage depth and forward speed on draught of three primary tillage implements using a tension load cell in clay loam soil were investigated. The implements included a mouldboard plough, a disc plough and a chisel plough, each of them with one tillage unit. A photoelectric speed sensor was used for measuring forward speed. The effects of forward speed and tillage depth on draught measurements were investigated through strip-split plot design. The effects of tillage depth and forward speed at on draught were highly significant at ($P \geq 0.01$). Comparison of average draught in treatments with Duncan's Multiple Range Test showed that mouldboard plough in highest forward speed and tillage depth had maximum draught and disc plough in lowest forward speed and tillage depth had minimum draught values.

Similarly, Ani, *et al.* (2007), studied the suitable condition for tractor operation using disc plough on loamy sand soil of Ilorin ecological zone. In a randomized complete block design (RCBD), the tractor trace technique was used to measure draught with dynamometer and cone index was also measured. Trafficability prediction equation initially developed by Wismer and Luthd (1981) was applied as follows;

$$\frac{TF}{W} = 1.21 - \frac{5.23}{Cn} \tag{7}$$

$$\frac{P}{W} = 2.24\ (\rho^{-0.02\ Cns}) \tag{8}$$

$$C_n = \frac{Ci\ bd}{W} \tag{9}$$

Where;

TF = towing force (N)
W = Tire load (kg)
C_i = Cone index (cm)
C_n = Soil wheel numeric
b = Tire width (cm)
d = Tire diameter (cm)
s = Tire slip (%)

A disc ploughing was carried out on an experimental plot at thirteen different soil moisture levels ranging from 8.90 % to 91.74 % of field capacity. The tire slip and wheel sinkage measured at each moisture level was used to analyzed tire slip which was either less than or equal to 15 %. The corresponding soil moisture range was selected as the soil moisture condition at which the soil was tractable between soil moistures of 8.90 % to 60.08 % of field capacity. It was also found that the differences in soil moisture distribution along the slope of the land had no significance at $P \geq 0.05$ effect on the towing force and the drawbar pull of the tractor. Regression analysis of soil and machine parameters was used to establish the soil moisture range at which the soil is tractable as well as the trafficability prediction equation. The study found that the soil was tractable at 60% field capacity and below. Soil Moisture above this value may lead to loss of output. This established a tractability condition for operations with disc plough on the loamy sand soil of Ilorin agro-ecological area. (Ani *et al.,* 2007).

Olatunji and Davies (2009) investigated the relationship between increase in weight of disc plough, tillage depth and draught using dimensional analysis on sandy loam soil. The field study was carried out with three different soil moisture levels and five levels of operation speeds (0.83, 1.39, 2.5, 1.94 and 2.78 m/s). it was observed that draught increased with increase in depth of penetration and soil moisture.

Majid *et al.* (2013) reported on a study on the effect of machine operational parameters in relation to soil moisture for the study area (mazandari province of Iran). A factorial experiment was designed in a randomized complete block design (RCBD) with three replications by. The statistical analysis of the study indicated that, the effect of moisture content, tillage depth and operating speed on draught force were significant at ($P \geq 0.05$) level. The study also revealed that draught force decreased by increasing soil moisture content and increased with increase in tillage depth and operating speed. In a relative investigation, Rashidi *et al.* (2013) conducted a study on the effect of soil moisture content, tillage depth and forward speed of an implement on draught force of double action disc harrow. A factorial experiment was carried out in a randomized complete block design (RCBD) with three replications. The data collected were subjected to analysis of variance (ANOVA). Also, Duncan's Multiple Range Test (DMRT) at 5% probability was performed. The study showed that soil moisture content, tillage and forward speed were significant at ($P \geq 0.05$) as it affected draught force. It also indicated that, draught force decreased with increased soil moisture content but increased with increase in tillage depth and forward speed. The investigation also revealed that tillage depth and forward speed had less influence on draught force with increasing soil moisture content, whereas forward speed had more influence on draught force with increasing tillage depth.

An investigation on the influence of tillage depth, penetration angle, and forward speed on a soil thin blade interaction force by Moeenifar *et al.* (2014), the variables tillage depth, tilt angle of and forward speed on draught were measured. Using dimensional analysis, a theoretical model for predicting the blade force was developed. The variables involved in the applied force of a soil working blade (p) are as presented; -

$$p = f(v, d, w, a, y, c, c_a, \varphi, \delta, q) \tag{10}$$

Where;

p = applied force of the soil working blade
v = velocity
d = depth
w = tool width
y = specific weight
φ =cohesive properties of soil
δ = adhesive properties of soil
q = surcharge

With an assumption that, q is generally absent in operation of the thin soil blade and influences of angle φ and δ are regarded as the cohesive properties of the soil, thus, there absence can be accepted. Also, for their similarities, both adhesive and cohesive properties could be merged together. Considering Buckingham's theory, the number of variables and repetitive invariants were seven and three respectively, and therefore, four constant pi-values were obtained. The three repetitive invariants were; velocity (v), specific weight (y) and tool width (w).

According to Mckyes (1985) approach on the assumptions that, the amount of soil pile increases with the distance traveled by the blade. For the soils pile in front of the blade the passive force was;

$$P = (y\alpha 2K_p + CdK_c + C_a dK_{ca} + qdK_q)^b \quad (11)$$

The horizontal blade H and vertical force V applied on the blade were as follows;

$$H = P\cos(\theta+\delta) + C_a db\cos\theta + F_m \quad (12)$$

$$v = P\cos(\theta+\delta) - C_a db + W \quad (13)$$

Where,

b = width of the blade (cm)

y = weight density of the soil (kg/cm^3)

d = cutting depth (cm)

C = cohesion of the soil

C_a = cohesion between the blade and the soil

q = surface pressure (kpa)

θ = the inclination angle of the blade (deg)

F_m = horizontal force applied on the mouldboard (N)

W = weight of the blade (kg)

K_p, K_c, K_{ca}, K_q = are the passive parameters

β = the failure angle (deg)

Similarly, Ranjbarian *et al.* (2015) developed a mobile instrumentation system and mounted on MF 285 tractor to measure the performance parameters of the tractor and attached implements. The result shows that, change in forward speed, implement type and their interaction are significant on draught ($P<0.05$). On a mouldboard plough, when the speed of implement was increased from 1.5 to 3km/h draught increases from 9 to 10 kN and was doubled. The American Society of Agricultural and Biological Engineering (ASABE, 2009) equation for draught prediction indicated that, by doubling the forward speed draught will also increase but will not double. The effect of forward speed and implement type on fuel consumption is also significant at ($P < 0.01$). Furthermore, fuel consumption decreased by an increase of velocity from 1.5 km/h to 3 km/h and increased by increase of velocity from 3 km/h to 4 km/h. Moreover, it was observed that draught requirement for implements in tests ranged from 8.2 kN for the disc plough to 13 kN for the chisel plough and fuel consumption of 10.72 L/ha for the chisel plough to 26.5 L/ha for the mouldboard plough. The ranges in mentioned parameters indicate that energy saving can be readily done by selecting energy-efficient implements and by proper matching of the tractor size and operating parameters to the implements.

This study focused on the matrix combinations of the tillage tools and operational parameters on the soils of northern and central Adamawa with the view to develop a mathematical model that encompasses the interaction of tools geometry and its operational parameters for an effective and efficient tillage operation in the area of study.

CONCLUSION

The review of research in this section indicated that, draught requirements of different tillage tools has been studied by many researchers on different soils studied the effect of implement parameters such as (tilt angle, disc angle, radius of curvature, gang angle, disc diameter etc) and the effect of interaction of these parameters on draught. Also, effect of operational parameters such as (speed, depth of cut, etc.) and the parameters of soil such as (moisture content, penetration resistance, shear strength, bulk density etc.) and the effects of their interactions on draught. Most of these result indicated that draught increased with increase in speed, depth of cut, weight of implement. Similarly, draught in some cases, depending on the nature of soil decreased with increase in moisture content of the soil, etc. However. Adamawa state is blessed with different type of soils with different behaviors, none of these studies analyzed the effect of interaction of tillage tool parameter on the soils of Adamawa state, Nigeria. In recommendation, the effect of tillage parameters on the soils of Adamawa state should be studied and the optimum draught requirement of the implement on that soil will be known.

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