Effects Of Depth And Speed On Power Requirements For Disc And Mouldboard Ploughs In Silt Loam Soils

Joseph Odero Alele, Godfrey M.N Ngunjiri, Musa R. Njue

Abstract: Effects of tillage depth and forward speed on draught power of primary tillage implements were studied using a pull dynamometer in silt loam soil. The implements used were a standard 2-bottom mouldboard plough and a 3-bottom disc plough. Tillage depths of 6.5 cm, 12.5 cm and 22.5 cm and speeds of 1.3 m/s, 2.3 m/s and 3.0 m/s were used. The effects of the treatments were studied using randomized blocks. There was significant increase in draught power with increase in tillage depth and forward speed at all the levels of the treatments tested for both the ploughs used. It was also noted that the draught power for mouldboard plough was higher than that in the disc plough at all levels of the parameters tested. Power requirement for mouldboard plough changed from 4.416 kW to 7.029 kW when tillage depth was varied from 6.5 cm to 22.5 cm. This results into an increase of 0.163 kW per unit change in depth of tillage. For the case of disc plough it increased from 3.344 kW to 6.404 kW which is equivalent to an increase of 0.191 kW. When speed was increased from 1.3 km/hr. to 3 km/hr. for disc plough power requirement increased from 2.911 kW to 7.048 kW resulting into an average change of 2.434 kW for the corresponding change in speed. While for the mouldboard plough the change was 3.12 kW within the same range.

Index Terms: Depth, Draft, Draught power, Dynamometer, Net draft, Plough, Speed, Tillage, Towed force

1.0 INTRODUCTION

Soil tillage is the mechanical manipulation of soil in order to improve soil conditions for crop production. It represents the most costly single operation for famers and the most tasking to the tractors [1]. The objectives of tillage include; production of a suitable tilth or soil structure, control of soil moisture, destruction of weeds and pests, and burying of organic material to add humus to the soil. Use of Agricultural mechanization is considered the main factor contributing to the total energy inputs in agricultural system and tillage is one area where massive power is used. The three items that are involved in tillage are; the source of power, the soil and the implement [2]. Condition of the soil at tillage time and capacities of the implements and tractors have to be properly understood before selection and matching for a particular task. Proper selection and matching of implements to tractors is a major factor in reducing energy consumption and breakages that occur on implements and tractors as a result of under loading or overloading. It is recognized that the application of energy-saving methods can make effective contributions to economy[3]. This can be possible by choosing economical and effective field operation methods in all agricultural areas [4].

- *Joseph O. Alele, Faculty of Engineering and technology, Egerton University P.O.Box 536 Egerton Kenya, Tel:+254721647747, E-mail: alelejnr@yahoo.com*
- *Prof. Godfrey M.N Ngunjiri, Faculty of Engineering and technology, Egerton University P.O.Box 536 Egerton Kenya*
- *Dr. Njue M.R Faculty of Engineering and Technology, Egerton University, P.O Box 536, Egerton, Kenya*

As fuel costs continue to rise, farmers must become more efficient fuel users. Shelton and Rider (5) outlined the following practices that can be used to reduce fuel consumption without adversely affecting production levels: reducing tillage trips over the field, reduced tillage systems, ballasting tractors, matching tractors and implements, selecting travel and engine speeds, and maintaining engines in optimum operation conditions. Of all the interventions listed above, proper tractor-implement matching is critical and this only possible when power requirement is established for the field soils and operating parameters like speed and depth and studied [6]. Factors that affect power requirement of implements tillage depth, moisture content, working width, geometry and stability arrangement of implements and forward speed [7].

2.0 MATERIALS AND METHODS

2.1 Experimental Set up

Two tractors were used for the field experiments and the set-up was as shown in Fig 2.1. Tillage implement was hitched on the three-point hitch system of tractor B so that the depth of tillage was controlled using the tractor hydraulics. Tractor A was used to pull tractor B and tillage implement through the load cell during operations.

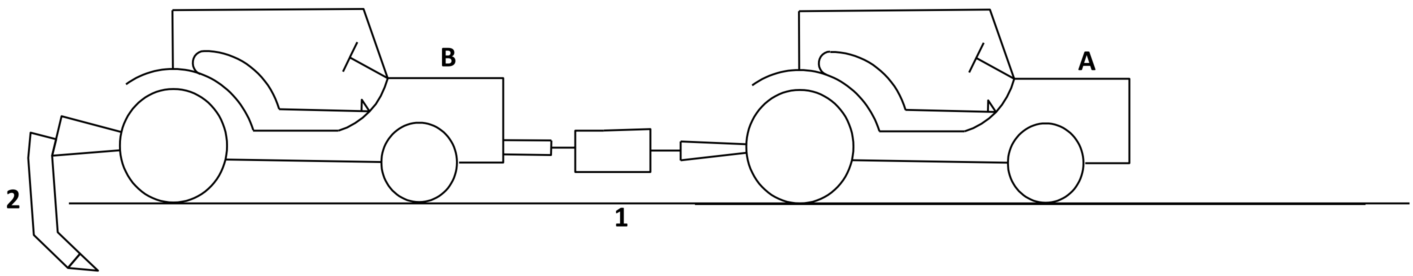

Fig 2.1 *Experimental set-up comprising of two tractors and load cell*

A - Tractive tractor
B - Tractor hitched with the tillage tool
1 - Load cell
2 - Tillage tool

The size of the plot required was done based on the number of variables and their replications. The numbers of variables were three; depths and speeds, and two tillage implements. The various depths that were used were denoted as (D1, D2 & D3), the speeds denoted as (S1, S2, & S3) and the two implements were disc and the mouldboard ploughs. The depths used were varied from 0 cm to 30 cm at a range of 10 cm. The speeds used were 1.3 km/hr, 2.3 Km/hr and 3.0 Km/hr. These speeds were chosen since they were easily attainable on the tractor used with three replications for every set-up.

The plot was further divided into 18 blocks and pegs placed at the start and end of every block. Each block was a square of 30 m by 30 m with inter block space of 10 m to allow for turning of the tractor. Soils samples were collected randomly from each of the plots. Draft readings were taken by a digital dynamometer which was remotely connected to a display that was in turn connected to the computer to allow for automatic saving of data obtained. The operator of the display system and the computer was located at the midway of the land clear of any obstacles.

Fig 2.2 *Dyna-Link 2 tension dynamometer set-up (Measuring Systems International 7300)*

The digital dynamometer allowed for automatic reading of draft values and direct storage into the computer. It uses disposable cells as the source of power with the display unit having in-built rechargeable battery.it has shackles at both ends to allow for mounting to the two tractors. Calibration was done to change: units of the draft values, the accuracy level and how the draft value will be recorded.

2.2 Power Determination

The draft values were measured at various depths and speeds for both the disc and mouldboard plough and recorded as gross force. The towed force was then determined for each field and at each speed which was later subtracted from the gross to get net draught force.

$$\text{Net draft (kN)} = \text{Gross draft} - \text{Towed force} \qquad (2.1)$$

Where;
Gross draft is total force measured when the rear tractor has the tillage implement lowered into the ground to the required depth and moved at the required speed Towed force is force measured when the rear tractor has the tillage implement raised from the ground and moved at the required speed. The net draft was then multiplied with the speed of operation to give the power requirement. This set of data was then used in analysis to establish the effects of depth and speed on power requirement for disc and mouldboard plough in silt loam soils.

3.0 RESULTS AND DISCUSSION

3.1 Preliminary site study

The soils in the experimental site were sampled and tested for soil texture, moisture content and bulk density. The percentages of sand, silt and clay were obtained as 37%, 51% and 12% respectively and the soil classified as silt loam using the textural triangle. Moisture content at the time of experiment was found to be 27% at 6.5 cm and 26% at 12.5 and 22.5 cm depths. Bulk density was found to be 1.30 g/cm^3, 1.40 g/cm^3 and 1.36 g/cm^3 at corresponding depths.

3.2 Effects of Depth and Speed on Power Requirement by Disc and Mouldboard Ploughs

Effects of depth and speed of operation on draught power for disc and mouldboard ploughs are as shown in Table 4.1.

Table 3.1 *Power in kW at various depths and speeds for disc and mouldboard ploughs*

Implement		Speed (km/hr)		
	Depth(cm)	1.3	2.3	3
Disc plough	6.5	1.844 ± 0.045	3.463 ± 0.170	4.725 ± 0.025
	15	3.090 ± 0.146	5.595 ±0 .265	7.492 ± 0.249
	22.5	3.798 ± 0.354	6.489 ± 0.500	8.926 ± 0.228
Mouldboard plough	6.5	2.299 ± 0.159	4.038 ± 0.103	6.910 ± 0.426
	15	3.311 ± 0.165	6.246 ± 0.147	8.610 ± 0.350
	22.5	3.842 ± 0.285	7.395 ± 0.375	9.851 ± 0.524

3.2.1 Effects of Depth of Ploughing on Power Requirement at different levels of speed

As shown on Table 3.1 and Fig 3.1 for the disc plough, power increased with increasing depths. These result concur with the observations made by Mamman and Oni **(8)** who observed that power increased at all levels of depth when experiment was carried out at 2.5, 5.0, 7.5 and 10.0cm. Abdallah **(1)**, carried out experiments at depths of 10, 15 and 20 cm which also gave similar observations with the disc plough. When the speed of tillage was 1.3 km/hr (0.36 m/s) as depicted on Figure 3.1, power increased from 1.844KW to 3. 798 kW with the depth varied from 6.5cm to 22.5cm. This translates to an increase of 0.122kW per centimeter increase in tillage depth. At a speed of 2.3 km/hr and depth varied at similar range, power increased from 3.463 kW to 6.489 kW giving 0.189kW increase per centimeter change in tillage depth. Similarly, at 3km/hr power increased from 4.725 kW to 8.926 kW equivalent to 0.263kW increase per centimeter.

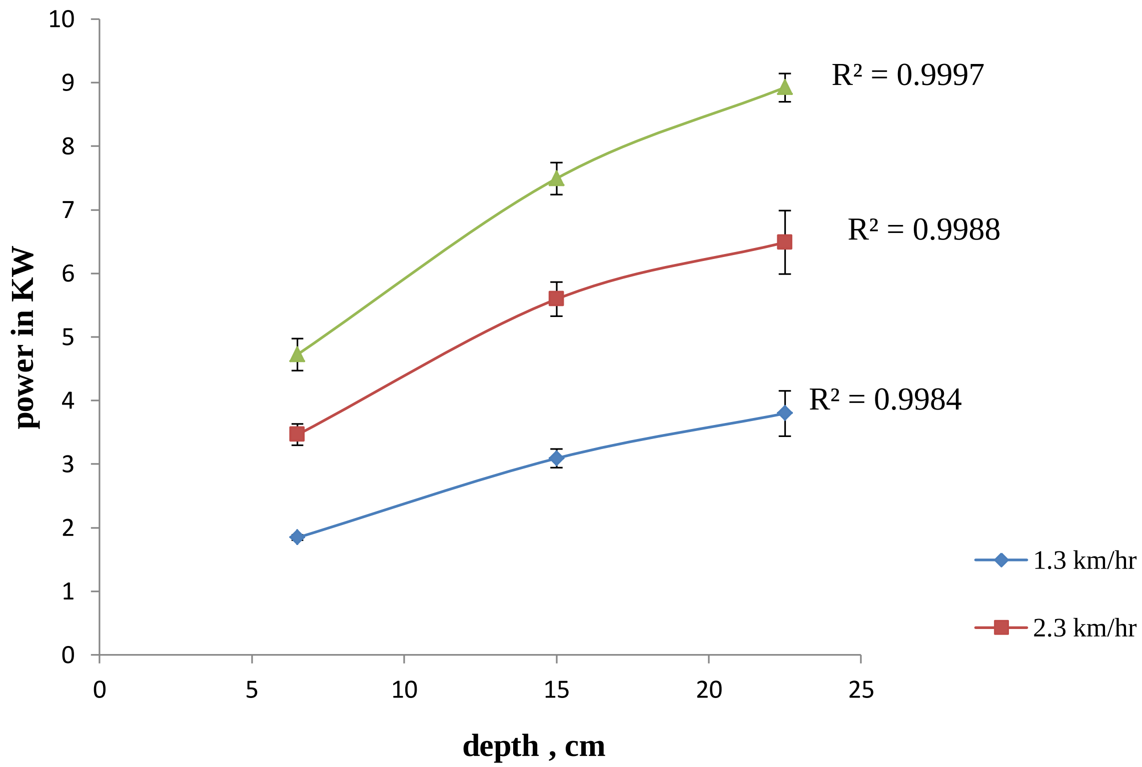

Fig 3.1 *Power against depth for disc plough*

Results for mouldboard plough presented in Fig 3.2 shows that power increased with increase in tillage depth, which is also in agreement with earlier studies by [1, 8-11]. At a speed of 1.3km/hr power increased from 2.299kW to 3.842kW which is equivalent to 0.053kW per centimeter increase in depth. While operating at 2.3km/hr power increased from 4.031kW to 7.395 kW resulting into a change of 0.210kW per centimeter. The highest was at 3km/hr when power increased from 6.910 kW to 9.851kW which is corresponding to an increase of 0.184 kW per centimeter.

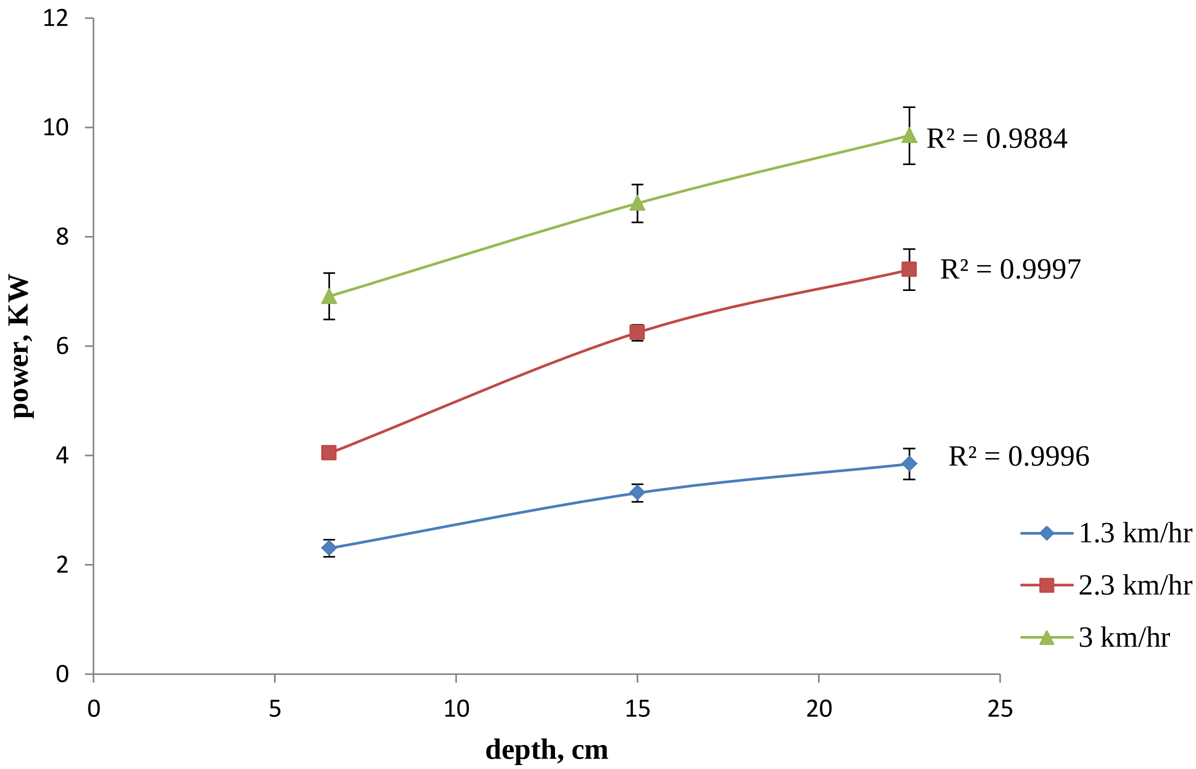

Fig 3.2 *Power against depth for mouldboard plough*

Comparison of the effect of depth on power by the two primary tillage implements shows that at all levels of depth, mouldboard plough had highest power requirement as compared to the disc plough as shown in Table 4.2 and Fig 3.3.

Table 3.2 *Power in kW at various depths for the disc and mouldboard ploughs*

PARAMETER	IMPLEMENT	
Depth (cm)	DISC	MOULDBOARD
6.5	3.344	4.416
12.5	5.393	6.056
22.5	6.404	7.029

Table 3.2 and Fig 3.3 shows the relationship between depth of tillage and draft power given by y = -0.0039x2 + 0.2777x + 2.7776 with R^2 = 1 for mouldboard plough and y = -0.0066x2 + 0.3837x + 1.1304R^2 = 1 for disc plough. This shows a strong relationship between the factors tested. Power requirement for mouldboard plough changed from 4.416kW to 7.029kW when tillage depth was varied from 6.5cm to 22.5cm. This results into an increase of 0.163 kW per unit change in depth of tillage. For the case of disc plough it increased from 3.344kW to 6.404kW which is equivalent to an increase of 0.191 kW. This indicates slightly higher increase rate for the disc as compared to mouldboard plough even though the later has higher power requirements. This observation concurs with among others, Naderloo, Alimadani (10) who carried out a similar study clay loam soils at depths of 10, 17 and 22cm.

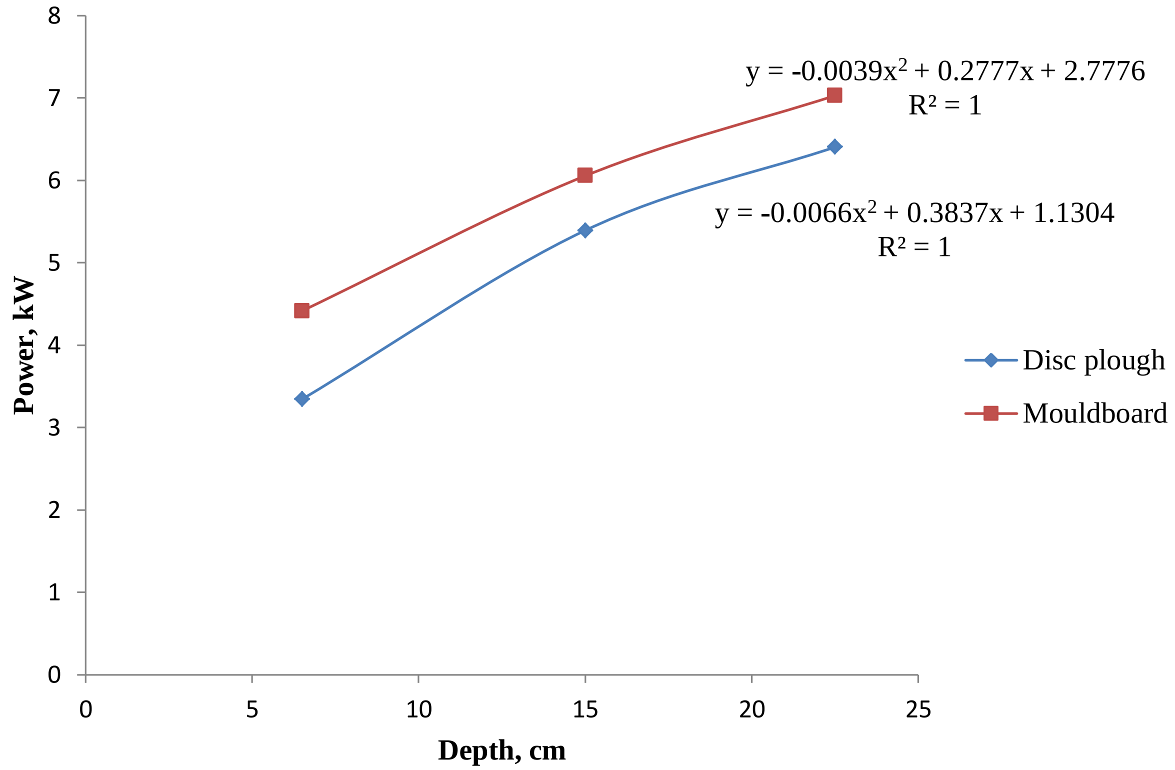

Fig 3.3 *Power against Depth for disc and mouldboard plough*

Increase in draft power at different tillage depths can be attributed to the increased volume of the mass of soil being supported and moved forward by the plough bottom which is much in the mouldboard because of geometry of its bottom.

4.2.2 Effects of Speed of Ploughing on Power Requirement at different levels of Depth

Fig 3.4 shows the relationship of power and speed of tillage for disc plough at various depths of tillage.

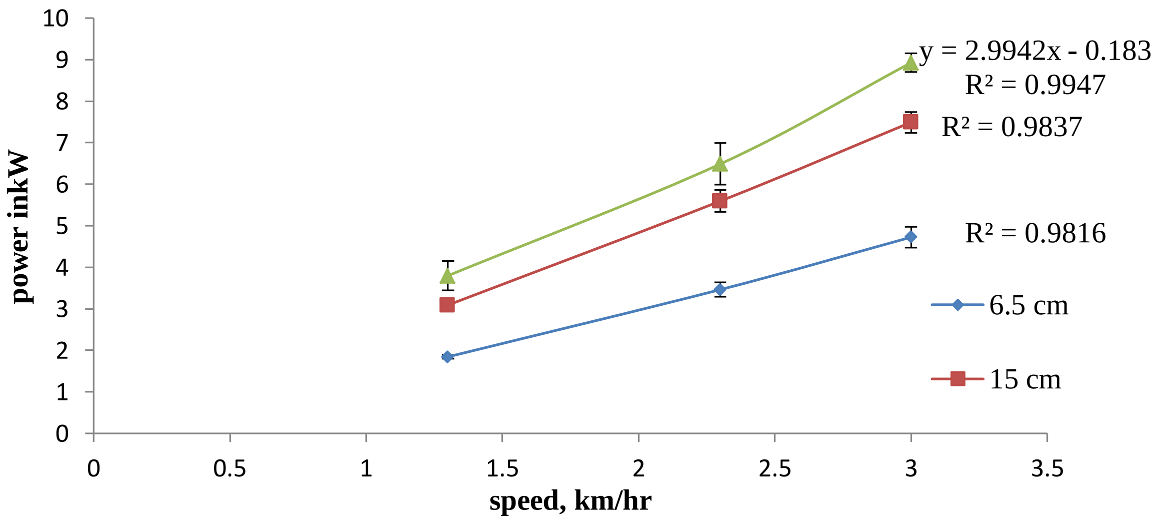

Fig 3.4 *Power against speed for disc plough*

Power was found to increase with increase in speed of tillage. The value increased from 1.844kw to 8.926 kW while the speed was increased from 0.36m/s to 0.833m/s. This agrees with studies by Kushwaha and Linke (9), which showed that power increased linearly speeds below critical range but less above speed range of 3 to 5m/s. This increase in power with increase in speed can be as a result of the high acceleration of the cut soil slices as they are displaced and turned by the plough bottom. Similar results are shown on Fig 3.5 for mouldboard plough. [Al-Janobi and Al-Suhaibani (12)], concluded that speed significantly affected power requirement by tillage implements when they conducted their study in sandy loam soils.

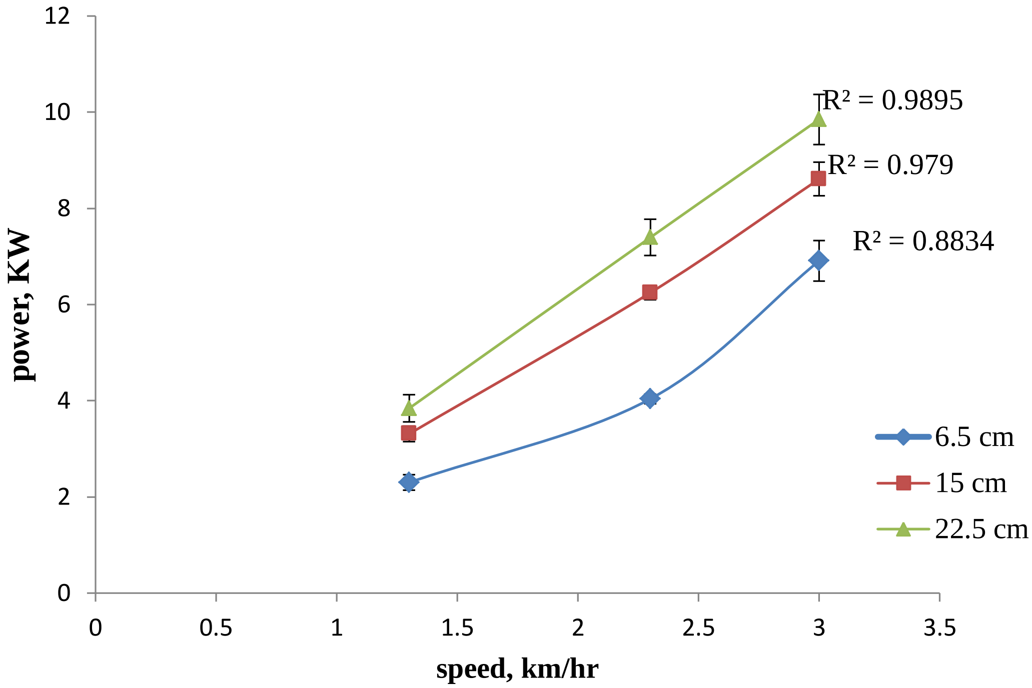

Fig 3.5 *Power against speed for mouldboard plough*

Fig 3.6 compares the effect of forward speed on power requirement by the disc and mouldboard plough with resulting linear regression equations given by y = 3.0955x - 0.9765 with a coefficient of determination R^2 = 0.993 for mouldboard plough and y = 2.4224x - 0.2824, R^2 = 0.998 for the disc plough. Ranjbarian, Askari (11), in their study found similar draw bar power prediction equations given by $y = 3.6777x - 2.1443$, R2 =0.9831 for mouldboard and $y = 3.8272x - 2.7457$, R2 = 0.9799 for disc plough. The slight differences in the two studies could be as a result of variations in soil characteristics. In both cases there is increase in power requirement with the mouldboard plough having the highest increase in power. When speed was increased from 1.3km/hr. to 3km/hr. for disc plough power requirement increased from 2.911kW to 7.048kW resulting into an average change of 2.434kW for the corresponding change in speed. While for the mouldboard plough the change was 3.12kW within the same range. This shows that the mouldboard plough is more sensitive to changes in speed as compared to the disc plough and this can be attributed to fixed nature of the mouldboard bottom which leads to dragging of the soil and any other material forward at these high speeds.

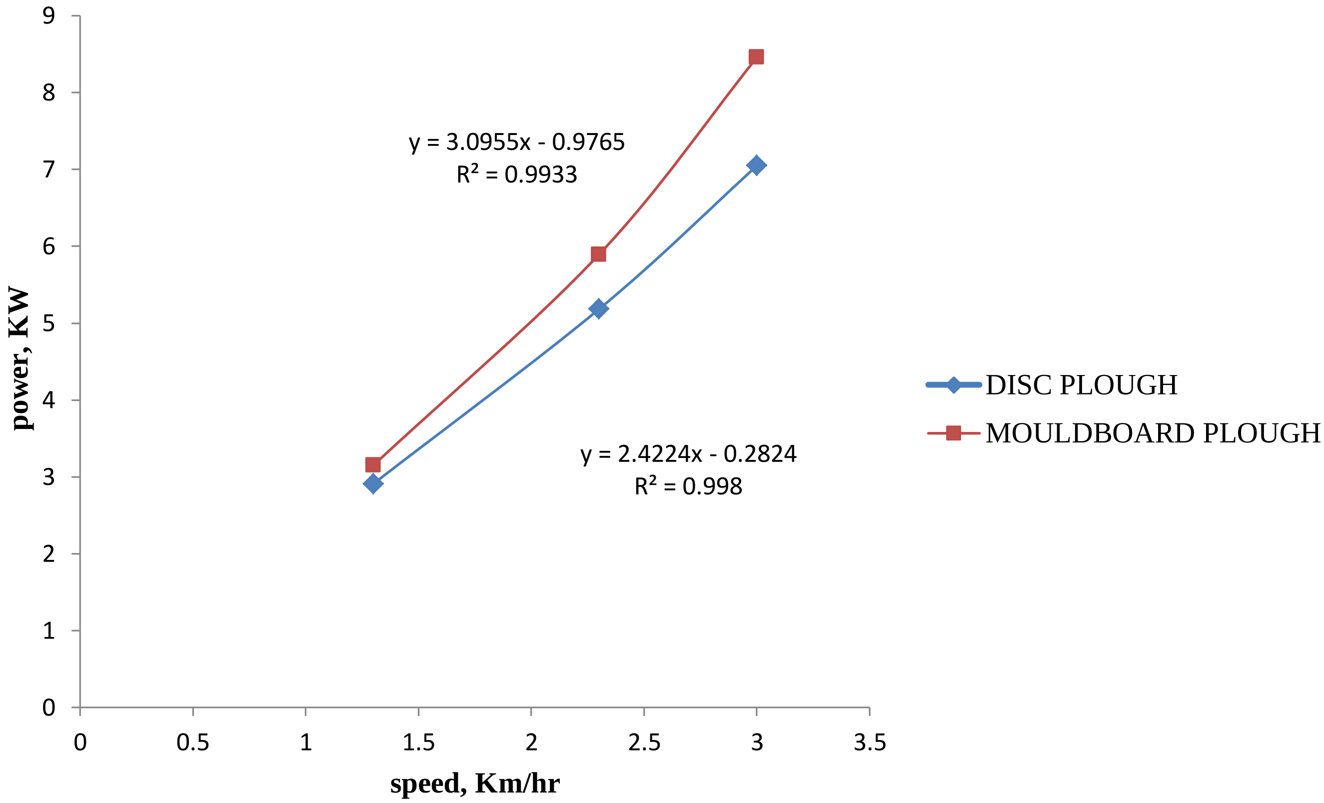

Fig 3.6 *Power against speed for disc plough and mouldboard ploughs*

Tables 3.3 and 3.4 gives an analysis of variance on the effects of depth and speed on power requirement by disc and mouldboard plough respectively.

Table 3.3. *Effects of parameters on power requirement by disc plough ANOVA*

Source of Variation	SS	df	MS	F	P-value	F crit
depth	14.58545	2	7.292727	21.99963	0.006945	6.944272
speed	25.75471	2	12.87735	38.84652	0.002397	6.944272
Error	1.325972	4	0.331493			
Total	41.66613	8				

Table 3.4 *Effects of parameters on power requirement by mouldboard plough ANOVA*

Source of Variation	SS	df	MS	F_{cal}	P-value	F crit
depth	8.014361	2	4.00718	19.43691	0.008704	6.944272
speed	42.40844	2	21.20422	102.8515	0.000364	6.944272
Error	0.824654	4	0.206163			
Total	51.24745	8				

MS-Excel software was used to run statistical analysis on data to investigate the effect of depth and speed on power requirement and results presented as shown on Tables 4.3and 4.4 for disc and mouldboard ploughs respectively. At 95% confidence level ($P<0.05$) the p-values were found to be less than 0.05 for all the parameters and implements used in this study. This shows that depth of tillage and speed significantly affect power requirement by disc and mouldboard plough.

4.0 CONCLUSION

Tillage depth and forward speed both led to increase in power requirement for the implements. Analysis of variance of variables at 95% confidence level showed p-values less than 0.05 indicating that depth and speed had a great effect on tillage power requirement. The mouldboard plough had highest values of power requirement at all levels of the parameters investigated. While the increase in power requirement per unit increase in speed was slightly higher for disc plough.

ACKNOWLEDGEMENT

The author thanks the African development Bank for financial support and Egerton University for the provision of laboratory services.

5.0 REFERENCES

[1] Abdallah AB. Effect of ploughing depth and speed of three tillage implements on tractor performance: UOFK; 2015.

[2] Olatunji O, Davies R. Effect of weight and draught on the performance of disc plough on sandy-loam soil. Research Journal of Applied Sciences, Engineering and Technology. 2009;1(1):22-6.

[3] Javadi A, Hajiahmad A. Effect of a new combined implement for reducing secondary tillage operation. International Journal of Agriculture and Biology. 2006;8(6):724-7.

[4] Bayhan Y, Kayisoglu B, Gonulol E, Yalcin H, Sungur N. Possibilities of direct drilling and reduced tillage in second crop silage corn. Soil and tillage research. 2006;88(1):1-7.

[5] Shelton DP, Rider AR. CC277 Energy Management in Field Operations. 2014.

[6] Sahu R, Raheman H. Draught prediction of agricultural implements using reference tillage tools in sandy clay loam soil. Biosystems Engineering. 2006;94(2):275-84.

[7] Al-Janobi A, Al-Hamed S, Aboukarima AM. An Excel Spreadsheet to Estimate Performance Parameters for Chisel Plow-Tractor Combination Based on Trained an Artificial Neural Network. Bulletin of the University of Agricultural Sciences & Veterinary Medicine Cluj-Napoca Agriculture. 2010;67(2).

[8] Mamman E, Oni K. Draught performance of a range of model chisel furrowers. Agricultural Engineering International: CIGR Journal. 2005.

[9] Kushwaha R, Linke C. Draft-speed relationship of simple tillage tools at high operating speeds. Soil and Tillage Research. 1996;39(1-2):61-73.

[10] Naderloo L, Alimadani R, Akram A, Javadikia P, Khanghah HZ. Tillage depth and forward speed effects on draft of three primary tillage implements in clay loam soil. Journal of Food, Agriculture and Environment. 2009;76(3):382-5.

[11] Ranjbarian S, Askari M, Jannatkhah J. Performance of tractor and tillage implements in clay soil. Journal of the Saudi Society of Agricultural Sciences. 2017;16(2):154-62.

[12] Al-Janobi A, Al-Suhaibani S. Draft of primary tillage implements in sandy loam soil. Applied engineering in agriculture. 1998;14(4):343-8.