

Comparative study on selected animal drawn tillage implements in sandy loam soil, Yola, Nigeria

Kabri, H. U., Umar, B. and Abubakar, A. J.

Department of Agricultural and Environmental Engineering, Modibbo Adama University of Technology, Yola, P. M. B. 2076, Yola, Adamawa State, Nigeria

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Abstract:

Animal drawn mouldboard and ridger ploughs are the most widely used primary tillage tool by farmers. Performance data on this implement is essential in order to reduce the cost of operation. Comparative study was conducted to determine the effects of speed and depth on draught and power requirements of these implements in sandy loam soil. A 2x3x3 factorial experiment arranged in a Randomized Complete Block Design (RCBD) in three replications was used. A general regression equation based the speed and depth of operation to predict draught and power requirements of the implements showed a significant increase in draught and power requirements with an increase in the speed and depth. The mouldboard plough was observed to have the highest draught and power means of 413.85 N and 517.31 J/s, then the ridger plough with draught and power requirements of 327.10 N and 408.88J/s obtained in speed-depth treatment (S_3d_3) of 1.05 m/s and 0.183 m respectively. The lowest mean draught and power values of 385.95 N, and 258.59 J/s for mould board and 285.25 N, and 191.12 J/s for ridger plough were obtained at speed- depth treatment (S_1d_1) of 0.65 m/s and 0.083 m respectively. The mean draught requirement of mould board plough exceeds that of ridger plough with about 23.88%. Analysis of Variance (ANOVA) showed that speed and depth had a significant effect at a 1 % level of probability ($P \leq 0.01$) on draught and power requirements. Similarly, the interaction between the speed and depth was statistically significant at a 1 % level of probability ($P \leq 0.01$). This study showed that the ploughing depth had more pronounced effect on draught and power than the speed. The regression equations can be suitable for predictive purposes for researchers, agricultural extension workers and designers during selection and design of animal-drawn tillage implements.

Corresponding author

Kabri, H. U.

hkabri@mau.edu.ng

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1. Introduction

Tractors implements, commonly used as primary tillage implements, have some limitations of high cost of implements and inefficient utilization on small farms. Under these conditions, significant improvements in the hand and animal-operated farm implement remain the most reliable, affordable, and one of the most important energy sources to raise crop yield and farmers' income [1, 2]. Tillage operation is the costliest energy and time-consuming operation among all other agricultural operations [3]. Selecting the most energy efficient tillage system often requires the field performance data of various tillage implements under varying local soil conditions. Unfortunately, the performance and energy data for many of these implements are very rare and not readily available to guide the farmers and other interested agencies in the regions in selection of suitable tillage implements [2 - 6].

Timeliness in agricultural operations and the techniques associated with its use right from the seed bed preparation to harvesting and threshing crops are essential for land labour productivity. This involves finding appropriate

ways and means to develop, introduce, and utilize the available and appropriate power source and implement combinations in our agricultural production system [3 - 6]. The youths in the rural areas where agricultural production is based are migrating into cities for employment thereby rendering insufficient manpower in the rural areas to perform various farm operations. [3] stated that agriculture is very sensitive to timely operations and weather conditions, and huge resources is spent on investment, therefore there is the need to evaluate the capacitive performance of agricultural machines for proper machinery selection, optimization and farm scheduling for timely crop production.

Draft and power requirements are important parameters for measuring and evaluating performance of tillage implements and therefore are considered to be essential parameters to correctly match a tillage implement to any source of power [2, 4, 7, 8]. Many studies conducted on draught and power requirements showed that the quality of work depends on soil type and conditions, manner of implement movement and shape [2, 5 - 8]. Animal drawn mouldboard plough and ridger plough has been and is still

the most widely employed primary tillage implement on the farm for primary cultivation, weeding and earthen up in Nigeria, due to its low cost and the availability of work animals such as oxen, cows, donkeys, horses and mules [1, 6, 8]. The present study is carried out to compare and evaluate the draught and power requirements of animal drawn single-furrow mouldboard and ridger tillage implements in sandy loam soils.

2. Materials and methods

2.1 Study area

The field study was conducted between June-July 2022 cropping season at the Research Farm of the Department of Agricultural and Environmental Engineering, Modibbo Adama University, Yola within the Savannah region located on latitude 90° 14'N, longitude 120° 32'E and at an elevation of 200 metres above sea level. The area falls within the Eastern Sudan Savanna ecological zone of Nigeria, marked by a dry season (November-April) and wet season (May-October) with mean annual rainfall usually ranging from 700mm to 1,050mm [9, 10]. The soil type in the area is sandy loam textures [6, 8, 9].

2.2 Experimental instrumentation

The major instrument used in the research work was a spring-type dynamometer (500 kg) used to measure the pull exerted on the mouldboard plough implement by the draught oxen. Other equipment included stopping watches used to measure and record the time taken to cover each run-in seconds. Steel measuring tape of 100 m long was used for the field layout and distance measurements. Steel meter rule of 30 cm long was used for depth and width measurement during the experiment. Wooden pegs were used for marking starting and ending points in the experimental field. Soil moisture meter (MD760) was used for in-situ moisture content determination on the field. AMS steel core soil samples were used to collect soil samples at various depth during the study. Graduated measuring cylinders were used to measure the volume of water. Electronic and spring weighing machine was used to measure the weight of soil samples both before and after operation for bulk density determination.

2.3 Treatment and experimental design

A 2x3x3 factorial experiment arranged in a Randomized Complete Block Design (RCBD) in three replications was used. A test plot of 1250 m² (50 m by 25 m) divided into nine sub-plots of size 16.7 m long x 8.3 m wide each was selected. This plot was replicated three times. The experimental treatments involved three speed levels (S) i.e., S₁, S₂, S₃ (0.65, 0.83 and 1.05 ms⁻¹) and three depth levels (d) i.e., d₁, d₂, d₃ (0.08, 0.12, and 0.15 m) for the study [6, 7, 8]. The tillage implements used are Ridger plough (*I*₁) and Mouldboard plough (*I*₂).

2.4 Field measurements

2.4.1 Determination of soil properties

Soil samples of the topsoil (0 – 15 and 15 – 30 cm) were obtained from the field before and after tillage using

the auger, core samplers, cutting blade and nylon bags for the laboratory determination of particle size analysis, bulk density and soil moisture content.

Soil texture classification was determined using the equation 1 given by [11]

$$S_p = \frac{(R - R_L \pm r)}{w} \times 100 \quad (1)$$

Where, S_p is the percentage of particles on suspension (%); R is the sample reading for hydrometer; R_L is the blank reading for hydrometer; r is the temperature correction factor (0.36); w is the weight of sample used (g).

The average soil moisture content was determined before and after each treatment by using an electronic soil moisture meter (MD760). The soil bulk density was determined by the core sample method as described by [11]. This involved taking three soil samples at random in a container from each test plot on the surface of 0-25 cm at 5 cm depth increment using a core sampler (4.35 cm diameter, 9.90 cm depth and 143.77 cm³ of volume) before and after ploughing. The bulk density was determined using the relationship given by [11]:

$$B_d = 4 \frac{W_d}{\pi D^2 h} \quad (2)$$

Where: B_d = Soil bulk density (g/cm³); W_d = Weight of dry soil (g); D = Internal diameter of core sampler (cm); h = Height of core sampler (cm).

2.4.2 Draught measurement

Before the actual field experiments, the operators and the work animals were retrained and rehearsed on a different field for three days on the variations in depth and speed of operation required during field work. Two white Fulani bulls (Zebu) aged between five and six years with a total weight of 538 kg (5277.78 N) and tractive capability of the oxen is 633.33 N (12% live weight) (Plate I) was used. The bulls were fitted with the implements, one at a time in carrying out the treatments.



Plate I. Draught Animals Used for Field Operation

This was due to the variations in speed of operation. The mean values were recorded for each treatment. The working height of both the yoke and the beam length was measured to determine the angle (α) beam makes with the ground. The actual draught was calculated using the equation 3 as reported by [12 - 14].



Plate II. Single-furrow mouldboard plough

$$D_R = P_f \times \cos \alpha \quad (3)$$

Where: D_R = Actual Draught (N); P_f = Tractive pull, (N); α – the angle of inclination of the chain to the horizontal (20°).

The implement was operated targeting each of the three working speeds ($S_1 = 0.65$ m/s, $S_2 = 0.83$ m/s and $S_3 = 1.05$ m/s) and depths ($d_1 = 0.083$ m; $d_2 = 0.128$ m and $d_3 = 0.185$ m) as recommended by [8] while ploughing with animal-drawn implement respectively. The depth of soil cut was measured with a plastic ruler at various points along the furrow, while the width of cut was taken at the distance between successive furrow edges to ascertain the average width for each plot. It was further confirmed by using the relation in equation 4 described by [12].

$$W_{wd} = \frac{W_l}{N_p} \quad (4)$$

Where: W_{wd} = working width (m); W_l = width of land (m); N_p = number of plough passes

The animal power (P_{AN}): was calculated by multiplying the draught required (D_R) and the animal field speed (W_{SP}) as shown in equation 5 measured in m/s.

$$P_{AN} = D_R \times W_{SP} \quad (5)$$

The working speed (W_{SP}) was calculated using equation 6 as reported in [14, 16, 17];

$$W_{SP} = \frac{D_w}{T_h} \quad (6)$$

Where: W_{SP} = working speed (m/s); D_w = Distance covered per run (m); T_h = theoretical time (sec.)

2.5 Statistical analysis

Descriptive statistics and SAS were used to analyse the data obtained while linear regression analysis and analysis of variance (ANOVA) were used to draw conclusions and interactions among variables

3. Results and discussion

3.1 Textural classification

Table 1 shows the results obtained from the soil analysis within the top 30 cm with about 64 % sand, 19 % silt and 17 % clay. Using the USDA soil classification texture triangle, the soil at the experimental site is sandy loam with the sand fraction constituting high percentage (63.75 %) in the constituent. This result is in agreement with the observation of [6, 7] on Yola and Samaru soils respectively. The result also showed an average soil moisture content (MC) value of 7.89 %, wet weight basis, average soil bulk density (BD) of 1.62 g/cm³ dry weight basis. The result conforms to that of [2, 7].

Table 1. Physical properties of soil at the study site

Depth (cm)	MC (% w.b)	BD (gcm ⁻³)	% Sand (200-000µm)	% Silt (2-20µm)	% Clay (<2µ)	Textural class
5-10	7.18	1.60	63.00	18.50	17.20	Sandy Loam
10-15	7.29	1.62	64.13	18.52	17.35	
15-20	9.19	1.64	64.13	18.52	17.35	
Mean	7.89	1.62	63.75	18.51	17.30	
Standev.	0.25	0.02				
CV (%)	3.05	1.03				
90 % (CI)	LL	1.60				
	UL	1.64				

*MC = Moisture content, BD = Bulk Density (dry basis), w.b = weight basis, CV = Coefficient of Variation, CI = Confidence Interval, LL = Lower Limit, UL = Upper Limit, standev. = standard deviation

3.2 Maximum draught and power requirements

Table 2 shows the results of the implement draught and power requirements obtained from the combination of speed and depth of operation used in the experiment for the two implements. The results shows that the mouldboard plough have the highest draught and power means of 413.85 N and 517.31 J/s, while the ridger plough have 327.10 N and 408.88J/s in speed-depth treatment (S_3d_3) of 1.05 m/s and 0.183 m. It was also observed that the lowest mean draught and power values of 385.95 N, and 258.59 J/s for mouldboard and 285.25 N, and 191.12 J/s for ridger plough were obtained at speed-depth treatment (S_1d_1) of

0.65 m/s and 0.083 m respectively. It showed that the lower the depth of operation the lower the draught and power of implements used and vice versa.

3.3 Influence of various speeds and depths on draught and power

This result shows that the more soil is cut and turned over by the implement operating at a deeper range result in high draught and power value. Similar trend was reported by [6, 7, 12 - 15]. Figures 1 to 4 illustrate the effect of tillage forward speed (S) and depths (d) on draught and power at different levels of tillage depths and speeds (S) levels.

Table 2. Maximum draught and power requirement means of the animal drawn ridger and mouldboard tillage implements

Sn	Treatment	Draught (N)		Power (J/s)	
		Ridger	Mouldboard	Ridger	Mouldboard
1	S ₁ d ₁	285.25	385.95	191.12	258.59
2	S ₁ d ₂	294.95	390.50	197.48	261.64
3	S ₁ d ₃	308.12	397.35	206.27	266.22
4	S ₂ d ₁	294.42	399.75	290.44	387.76
5	S ₂ d ₂	303.85	403.2	299.97	391.10
6	S ₂ d ₃	316.28	406.6	307.96	394.40
7	S ₃ d ₁	299.85	405.11	372.31	506.39
8	S ₃ d ₂	310.80	410.25	388.50	512.81
9	S ₃ d ₃	327.10	413.85	408.88	517.31
	Mean	305.53	401.40	295.88	388.47
	Maximum	327.1	413.85	408.88	517.31
	Minimum	285.25	385.95	191.12	258.59
	Stdev	11.92	8.52	78.93	102.15
	Cv (%)	3.9	2.1	26.7	26.3

Figure 1 and 2 shows that the relation between speeds of operation, draught and power of ridger plough is approximately linear at each of the three depths particularly at depth (d₂) of 10-15 cm. Draught force and power increased with an increase in working speed at various working depths (d₁=0.083 m, d₂=0.135 m, and d₃=0.183 m) of operation. At depth (d₁) the increase in draught from speeds S₁ to S₂ was 3.21% and 1.84% from S₂ to S₃, while at depth (d₂) it was 3.02% from S₁ to S₂ and 2.29% from S₂

to S₃. Depth (d₃) recorded 2.65% and 3.42% in draught increment for S₁ to S₂ and S₂ to S₃ speeds of operation respectively. Same was observed for power since power is obtained from the draught multiplied by the speed of operation.

Figure 3 and 4 shows that draught force and power increases with increase in working depth at different speeds (S₁=0.67m/s, S₂=0.97m/s, S₃=1.25m/s) of operation.

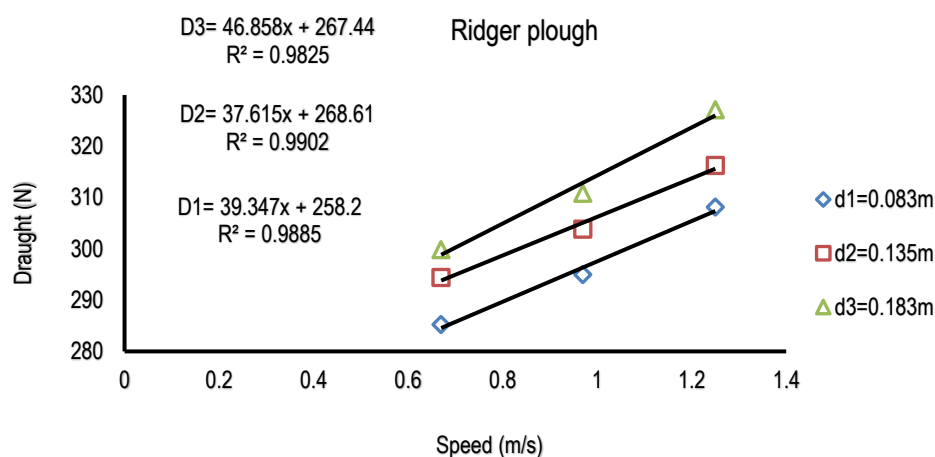


Figure 1: Effect of Speed (S) of Operation on Draught (D) at Various Tillage

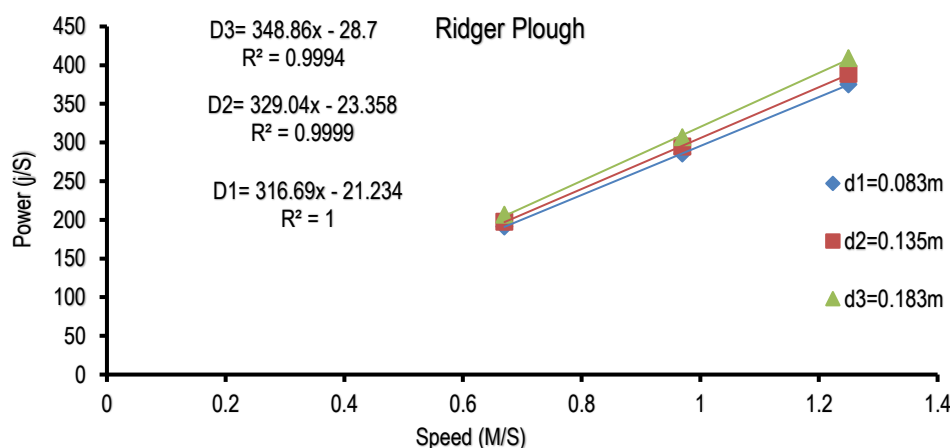


Figure 2: Effect of Speed (S) of Operation on Power (P) of Ridger Plough at Various Tillage

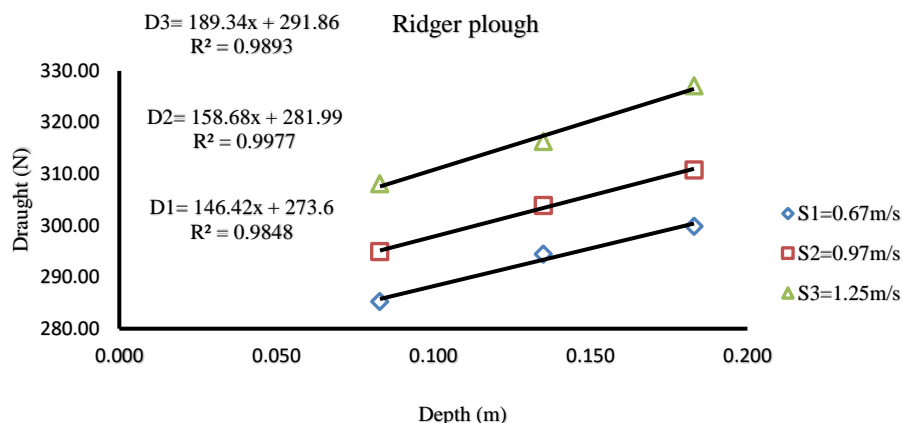


Figure 3: Effect of Depths (d) of Operation on Draught (D) at Various Tillage Speed

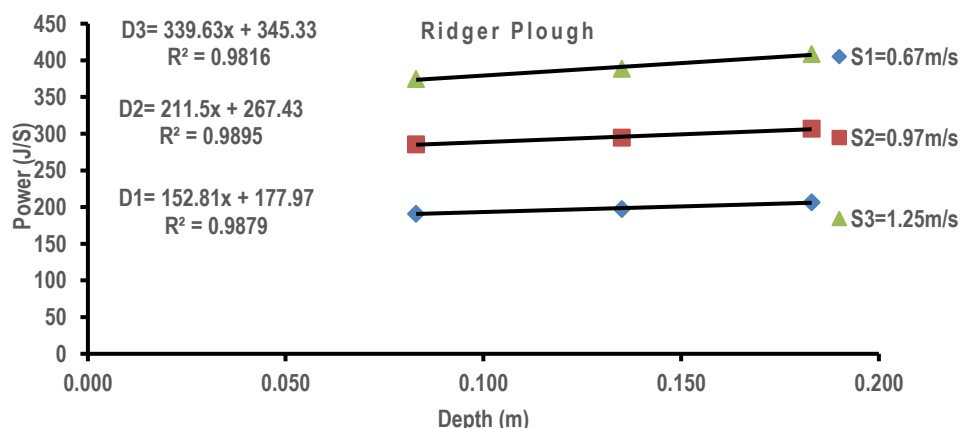


Figure 4: Effect of Depths (d) of Operation Power (P) of Ridger Plough at Various Tillage Speed

At speed (S_1) draught increase by 3.40% from d_1 to d_2 , 4.47% from d_2 to d_3 , while at speed (S_2) draught increased by 3.20% from d_1 to d_2 and 4.09% from d_2 to d_3 and speed (S_3) recorded 3.65%, and 5.24% from d_1 to d_2 and d_2 to d_3 respectively. Although both approaches of the linear regression analysis performed revealed a good correlation relationship between speed and depth of operation on draught power. The best fit equation was obtained at a speed and depth (S_2d_2) of 0.83m/s and 0.135 m with the highest r^2 values as shown in Figure 1 to 4. Similar trend was report by [2, 6, 7, 8, 15].

Figure 5 to 8 illustrate the effect of speed and tillage depth on draught and power of animal drawn mouldboard plough in sandy loam soil. There is a slight increment in draught and power as the speed increases with linear relation at each of the three tillage depths considered. Figure 5 and 6 shows that at depth d_1 (0.083 m), draught force increases by 3.58% when speed increase from S_1 to S_2 (0.67-0.97 m/s) and 1.34% from S_2 to S_3 (0.97-1.25 m/s), while at depth d_2 (0.135 m), draught force increases by 3.25% from S_1 to S_2 and 1.75% from S_2 to S_3 and at depth d_3 (0.183 m), draught increases by 2.33% from speed S_1 to S_2 and 1.78% from S_2 to S_3 .

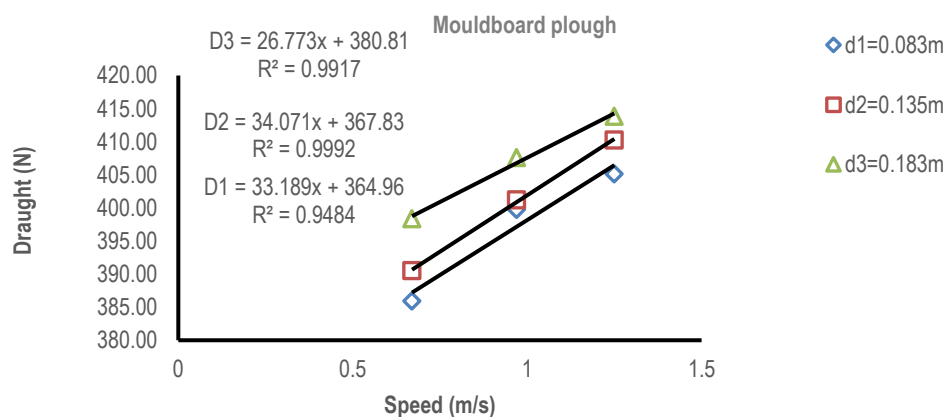


Figure 5: Effect of Speed (S) of Operation on Draught (D) at Various Tillage Depths (d)

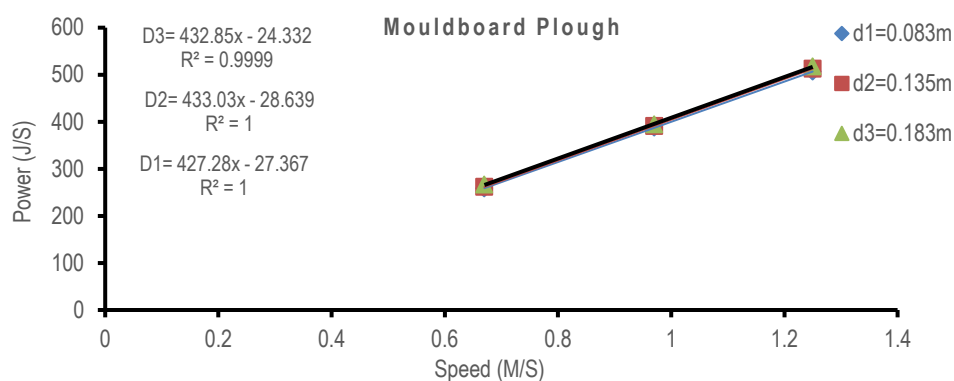


Figure 6: Effect of Speed (S) of Operation Power (P) of Mouldboard Plough at Various Tillage Depths (d)

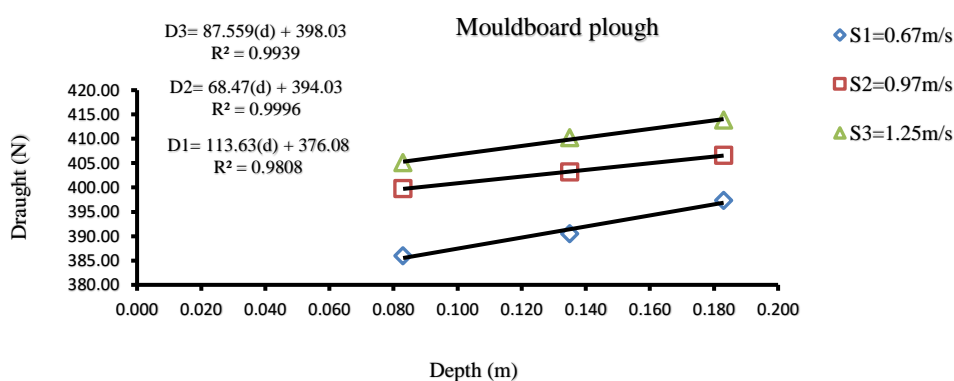


Figure 7: Effect of Depths (d) of Operation on Draught (D) at Various Tillage Speed (S)

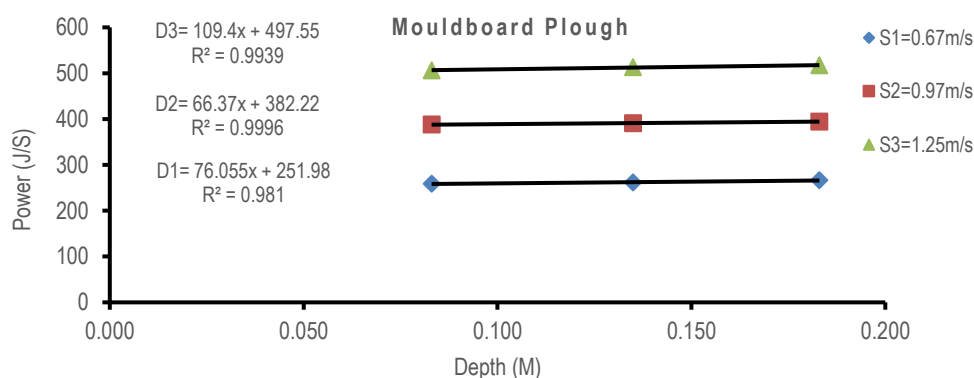


Figure 8: Effect of Depths (d) of Operation Power (P) of Mouldboard Plough at Various Tillage Speed (S)

Figure 7 and 8 shows that the draught and power increase with increase in tillage depths at each of the three speeds (0.67, 0.97, 1.25 m/s) of operation. At speed S_1 (0.67m/s) draught increase by 1.18% when depth increase from d_1 to d_2 (0.083-0.135 m), and 1.75% from d_2 to d_3

(0.135-0.183 m), while at speed (S_2), draught increase by 0.86% and 0.84% from depth d_1 to d_2 and d_2 to d_3 and at depth d_3 , draught force increases by 1.27% from depth d_1 to d_2 and 0.88% from depth d_2 to d_3 depths of operation. This result agreed with report of [2, 5, 7, 12, 14, 15].

Table 5 Analysis of variance (ANOVA) for draught force of two animal drawn tillage implements.

Sn	Sources of variation	Df	SS	MSS	F _{cal}	F _t	
1	Replication	2	245.8702	122.9351	11.142158	6.23	**
2	Implement (I)	1	247073.012	247073.012	22393.332		**
3	Speed (S)	2	10103.2241	5051.61205	457.8502	„	**
4	Depth (d)	2	6250.7605	3125.38025	283.26719	„	**
5	I x S	2	643.106	321.553	29.143787		**
	I x d	2	1526.657	763.3285	69.183877		**
4	S x d	4	637.6561	159.414025	14.448406	4.77	**
	I x S x d	4	416.1066	104.02665	9.4284006		**
5	Error	34	375.1332	11.0333294			
6	Total	53	267271.5257				

** = Significance at 1% probability level ($P \leq 0.01$); Df=degree of freedom, SS= sum of square, MSS=mean sum of square, F_{cal}=ratio of two variances calculated, F_t=critical standard value.

The linear regression analysis performed revealed that the relationship between both speed and depth with draught of mouldboard plough shows a very close good correlation of draught data to each other with r^2 closed to 1. The best fit equation was obtained at a speed and depth S_2d_2 (0.83m/s, 0.135 m) of operation with highest r^2 values as shown in Figure 5 to 8.

This study revealed that the effect of tillage depth and speed on draught of ridger plough was different from that of mouldboard plough. The mean draught requirement of mouldboard plough is more than that of ridger plough with about 23.88%. Tillage depth affect draught requirement of tillage implements more than that of speed. Similar results were reported by [4, 6, 7]. The analysis of variance (ANOVA) for the test of speed and tillage depth effect on draught for the two implements is presented in Table 5. The result showed that the draught of animal-drawn tillage implement is significantly affected by tillage depth and speed at 1% level of probability ($P \leq 0.01$).

The interaction between the two factors, three different forward speeds and tillage depths was also statistically significant at 1% level of probability ($P \leq 0.01$). The results showed that the animal-drawn tillage implements is optimally operated more economically at a mean speed of 0.97 m/s and a mean depth of 0.135 m. Similar results were reported by [1, 6, 7, 14, 15].

The results obtained from the present study showed that the ploughing depth had more pronounced effect on draught and power than the forward speed. Increasing the ploughing depth increased the volume of soil to be cut, moved and pulverized which required more force and power. Similar results were reported by [2, 4, 6, 8, 12, 15].

4. Conclusions

Comparative study was conducted to determine the effects of forward speed and tillage depth on draught and power requirements of two animal drawn tillage implements during tillage operation in sandy loam soil. A significant increase in draught and power requirements were observed for the two implements with an increase in the speed and depth. The mouldboard plough was observed to have the highest draught and power means of 413.85 N and 517.31 J/s, while the least draught and power requirements of 327.10 N and 408.88J/s were obtained on ridger plough in speed-depth combination (S_3d_3) of 1.05 m/s and 0.183 m. It was also observed that the lowest mean draught and power values of 385.95 N, and 258.59 J/s for mouldboard and 285.25 N, and 191.12 J/s for ridger plough were obtained at speed-depth treatment (S_1d_1) of 0.65 m/s and 0.083 m respectively. The mean draught requirement of mouldboard plough is more than that of ridger plough with about 23.88%. Analysis of Variance (ANOVA) showed that the speed and depth had a significant effect at a 1 % level of probability ($P \leq 0.01$) on draught and power requirements. Similarly, the interaction between the speed and depth was statistically significant at a 1 % level of probability ($P \leq 0.01$). The results showed that the animal-drawn tillage implements is operated more economically at a mean speed of 0.97 m/s and a depth of 0.135 m. The ploughing depth had more pronounced effect on draught and power than the

forward speed. Increasing the ploughing depth increased the volume of soil to be cut, moved and pulverized which required more force and power. The regression equations can be suitable for predictive purposes for researchers, agricultural planners, designers and extension workers during the selection and design of animal-drawn tillage implements.

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