Performance evaluation of a spring tine cultivator in a sandy loam soil

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Abstract: Selection and matching of appropriate tillage implements for a given farming operation are dependent on the data available on draft parameters for the particular tillage implement. Spring tine cultivator is one of the primary tillage implements commonly used by farmers in the study location. Performance information of spring tine cultivator is vital to enable the cost of tillage operation to be reduced. Field experiments were performed using Randomized Complete Block Design (RCBD) with three replications using spring tine cultivator and tractor at three tillage depths (10, 20 and 30 cm) and five tractor speeds (3.6, 5.4, 7.2, 9.0 and 10.8 kmhr^{-1}) to determine the implement travel speed. The effects of tillage depth and implement travel speed on draft force, unit draft, vertical specific draft, horizontal specific draft and coefficient of pull were accessed. The results showed that increasing the tillage depth or implement travel speed increased the draft force, unit draft and vertical specific draft. The relationship between them is also linear. Increasing the tillage depth equally increased the horizontal specific draft and the coefficient of pull but increasing the implement speed reduced the horizontal specific draft and the coefficient of pull. Approximately 27.5 % of the draft force was focused towards cutting the soil and 72.5 % was spent in pulverization of the soil particles. The values of the vertical specific draft were much more than those of the horizontal specific draft for all the tillage depths and the implement travel speeds. The tillage depth had more influence on the draft, unit draft, specific draft and the coefficient of pull than the implement travel speed.

Key words: tillage, draft, unit draft, specific draft, coefficient of pull, tractor, spring tine , cultivator

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1 Introduction

Many parameters such as type and condition of soil and tractor-implements characteristics affect the performance of tillage implements. Tillage depth, speed, texture and moisture content of soil are important parameters that have effect on the performance of tillage implements. Gathering of information is needed in order to evaluate adequately crop production and to be able to choose alternative crop production or tillage systems. In addition to the required tractor size, implement draft can also be used to determine the fuel consumption for an operation (Ismail and Burkhardt 1993).

Mamman and Oni (2005) investigated the influence of draft on the performance of similar models chisel furrows. The experiment was performed in a non-natural soil in an enclosed soil bin. The tool design factors studied were nose angle (10, 20, 30^0), slide angle (5, 10, 15, 20^0) and cutting edge height (2, 5, 10 mm). The operating factors used by them were tool speed of travel (0.02, 0.05, 0.10, 0.15 ms^{-1}) and depth of tillage (2.5, 5, 7.5, 10 cm). Their results indicated that the draft

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increased with increases in tool and slide angles, and cutting edge height. They reported that there was no optimum value of speed for which least draft occurred at these levels of depth, nose and slide angles, and cutting edge height considered. Their results indicated that tillage depth of 7.5 cm had more effect on the draft of the model implements.

The influence of draft on the performances of different tillage tools and implements in different countries were studied (Oni et al., 1992; Shirin et al., 1993; Fielke, 1996; Mckyes and Maswaure, 1997; Onwualu and Watts, 1998; Al-Janobi and Al-Suhaibani, 1998; Manian et al., 2000; Shestha et al., 2001; Gratton et al., 2003; McLaughlin and Campbell, 2004). It was reported that all these researchers observed that the draft force varies with variations in soil conditions, tool design, and operational factors.

Kushwaha and Link (1996) reported that draft requirements of tillage tools as dependent on the speed of operation are important criteria for assessing tillage implements either by field or laboratory testing. Taniguchi et al., (1999) reported an increase in draft with increase in speed of travel for a mouldboard plough and that there was a linear relationship between speed and draft. Grisso et al., (1996) measured the draft of a tandem disc, chisel plough and field cultivator in a silty clay loam soil on a wheat stubble field. The speed of travel and depth of tillage were used to investigate the draft of the tillage implements. They discovered that the drafts of the tillage implements were significantly influenced by both speeds of travel and depth of tillage. The draft for the tandem disc varied quadratic ally with depth when used as a primary tillage implements. The depth of tillage mostly affected the draft of the chisel plough. Although the direct influence of the speed of travel was found to be significant, speed showed little effect on the draft for chisel plough. The draft for the field cultivator was linearly dependent on speed and speed by depth interaction but quadratically dependent on depth. Fielke (1996) investigated the influence of the cutting edge geometry of tillage implements on tillage forces, soil failure and soil movement below the depth of tillage in the field and a laboratory soil bin. He used experimental sweeps that were standardized with 400 mm width; 32 mm lift height, 10^0 rake angle and 70^0 sweep angle. He reported that increasing the operating speed consistently increased the draft but had little influence on the vertical force.

Al-Suhaibani and Al-Janobi (1997) studied the influence of speed and depth on the draft of a chisel plough; an offset disc harrow, a mouldboard and a disc plough on sandy loam soil in the field. They observed a significant increase in the draft for all the implements with an increase in depth. The specific drafts of four tillage implements were also affected significantly by speed and depth. Mouazen and Nemenyi (1999) estimated the draft and vertical forces, soil deformation affected sign and normal pressure distribution on four geometrically similar subsoilers using the finite method. The four subsoilers investigated have a combination of a vertical shank with 15, 23 and 31^0 included chisels and a 75^0 rake angle shank with 15^0 inclined chisels. They reported that a subsoiler with a shank angle of 75^0 and a chisel angle of 15^0 had the least draft.

Celik et al. (2007) conducted field experiments on a wheat stubble field to compare specific draft and energy uses of experimental plow, disk plow and mouldboard plow. They measured plow draft, forward speed and fuel consumption with a test tractor equipped with fuel transducer, three hitch point transducer, ground speed radar and data logger. They carried out the experiment at a constant depth of 20 cm and tractor forward speeds of 4.5, 5.4 and 6.3 km hr^{-1}. Their results indicated that the specific draft, drawbar power and fuel consumption were affected significantly by plows and speeds. They also reported that lowest draft and drawbar power were obtained for the moldboard plow while lowest specific draft and fuel consumption were obtained for the experimental plow. Their findings also revealed that disk plow has the highest draft, specific draft, drawbar power and fuel consumption. Draft, power and fuel consumption increased with in increasing forward speeds.

Mudamburi et al. (2018) conducted studies over a period of three years at the Ogongo campus of the University of Namibia to compare the differences between two conventional tillage treatments i.e tractor-drawn disc harrow and animal-drawn moldboard plough and two Namibia specific conservative tillage treatments i.e tractor-drawn ripper furrower and animal-drawn ripper furrower. They reported that the Namibia specific conservative tillage technologies performed better in terms of the depths of cut than the conventional technologies in all the three years but that the Namibia specific conservative technologies also resulted in higher draught forces than the contemporary conventional technologies. Their results also showed that the specific draught of Namibia specific conservative technologies were less across the three seasons indicating that they were more energy efficient than conventional technologies. They also reported that the tractor-drawn tillage methods resulted in lower specific draught than animal-drawn tillage methods across the three years.

Jyoti et al. (2019) used pull type load cell along with an auxiliary tractor to determine the draft requirement of selected tillage implement. They observed that the draft requirement of mourdboard plough was maximum at 619 kg compared to disc plough, disc harrow and cultivator. Akashah and Hammed (2015) conducted an experiment to study tractor power requirement for chisel plough and an offset disc harrow. They studied the power requirements under wet and dry soil conditions and for two depths of work for each implement (20-30 cm and 5-10 cm). They investigated the effect of implement draught on the performance of 2 WD (120 hp) tractor in terms of wheel slip (%) under the field conditions of the experiment using different levels of wheel ballast. Their results showed that draught requirement for the chisel plough was between 11 to 15 kN and for disc harrowing, the values ranged between 7 to 10 kN.

Performance data for the operation of a spring tine cultivator is essential in order to minimize the cost of operation. The availability of published data on the evaluation of the performance of spring tine cultivator in the study location is currently not sighted. This has necessitated this research work in this area of soil tillage dynamics.

The main objective of this study is to evaluate the performance of a spring tine cultivator in a sandy loam soil. The specific objectives are to study the effects of tillage depth and implement speed on: (i) draft force (ii) unit draft (iii) vertical specific draft (iv) horizontal specific draft (v) coefficient of pull.

It is obvious that tillage depth and speed of operation have effects on the performance of any tillage implement. The extent of the effect of these parameters on the performance of a spring tine cultivator in a sandy loam soil was achieved through this research work.

2 Materials and methods

2.1 Tractor and tillage implement

The specifications of the tractor and the tillage implement used for the field experiment are presented in Table 1.

2.2 Experimental setup

The experiment was performed at Mbiabong, Uyo Local Government Area of Akwa Ibom State, Nigeria. Soil samples were collected during the tillage experiment to determine the soil conditions in which the experiment was performed. 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 110^{0}C for 24 hours. The dried soil samples were re-weighed and the weight was again recorded. The moisture contents were calculated on a dry weight basis.

2.3 Experimental layout and pattern

Three research plots measuring 100 m long by 50 m wide each were measured, marked and mapped out with pegs while a one-way pattern of ploughing operation as given by Ojhai and Michael (2006) for a rectangular field was adopted for the field experiment.

2.4 Experimental design and procedure

The parameters investigated for the evaluation of performance of a spring tine cultivator were three levels of tillage depth (10, 20 and 30 cm) and five levels of tractor speed (3.6, 5.4, 7.2, 9.0 and 10.8 kmhr^{-1}). During the field experiment, the tractor was operated at the same speeds for the different tillage depths. An experimental plot of 100 m long by 50 m wide was used for each 10, 20 and 30 cm tillage depths.

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. There were fifteen (15) runs, that is, in the factorial of $1\times3\times5$ (one implement, three tillage depths and five tractor speeds) replicated three times resulting in a total of forty five (45) runs. The different tractor speeds (3.6 - 10.8 km hr^{-1}) were achieved by selecting appropriate gears and adjusting engine throttle at engine speeds of between 1600 and 2000 rpm while the tillage depths (10 - 30 cm) were achieved by using tractor depth controller through its quadrant. Tillage depth was measured as a vertical distance from the top of the undisturbed soil surface to the implement's deepest penetration using a steel measuring tape. The time taken for the implement to travel a distance of 100 m was taken and recorded. The distance was divided by the time taken to obtain the implement travel speed.

Table 1 Specification of tested tractor and implement

Specification	Value	Parameter	Value
Manufacture	Swaraj tractor, model 978 FE	Type of hitching	Fully mounted
Effective output (hp)	72 (53.7 kW)	Total width of tillage (cm)	240
Type of engine	4-Cylinder	Number of tines	11
Type of steering system	Power assisted	Width of each tine (cm)	6
Fuel tank capacity (L)	98	Number of rows	2
Lifting capacity (kg)	1250	Number of tines in first row	5
Rated engine speed (rpm)	2200	Distance between tines in the first row (cm)	40
Country of manufacture	China	Rake angle (^{o})	49
Front tyres (size)	6.0x16 inches	Width of implement (cm)	66
Inflation pressure (kPa)	360	Number of tines in second row	6
Rear tyres (size)	14.9x28 inches	Distance between tines in the second row (cm)	40
Inflation pressure (kPa)	180	Weight of implement (kg)	266

Figure 1 Tractor with Spring Tine Cultivator used for the Field Operation

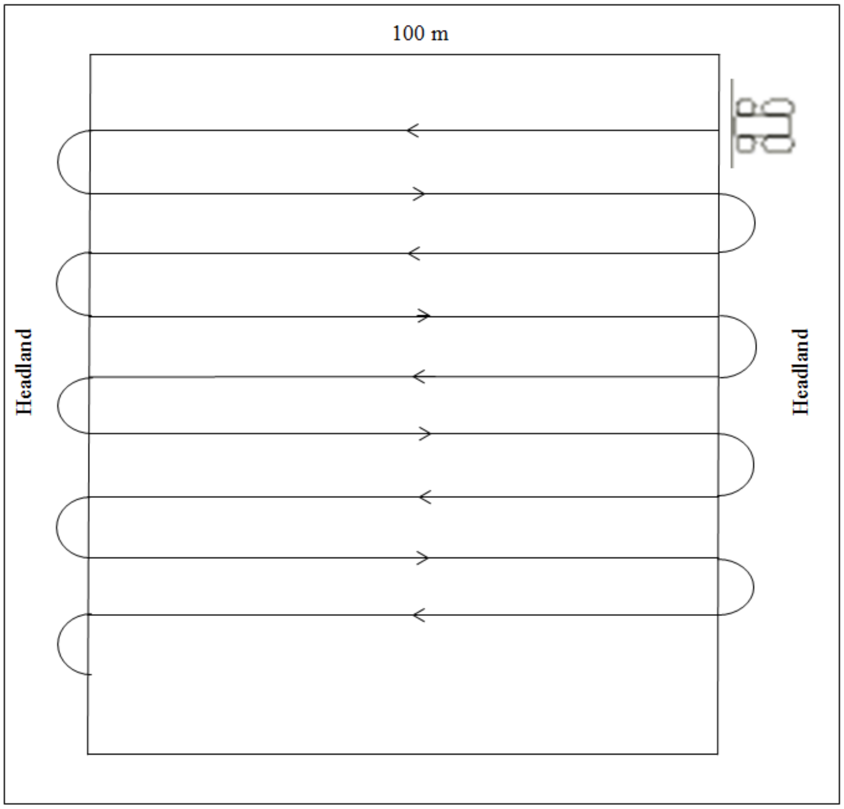

Figure 2 One-way Pattern of the Experimental Layout of the Field Operation

2.5 Determination of draft force

The draft force of the tillage implement was determined using the equation as given by Srivasta et al. (2006).

$$D = \frac{W}{Z} + \frac{c\left(\frac{bd}{sin\beta}\right) + \rho bdv_o^2 sin\delta / sin(\delta+\beta)}{Z(sin\beta + \mu cos\beta)} \quad (1)$$

Where,

D = Draft force 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 = implement travel speed, ms^{-1}

$$Z = \frac{cos\delta - \mu' sin\delta}{sin\delta + \mu' cos\delta} + \frac{cos\beta - \mu sin\beta}{sin\beta + \mu cos\beta} \quad (2)$$

μ' = coefficient of internal soil – metal friction

2.6 Determination of unit draft, vertical specific draft, horizontal specific draft and coefficient of pull

The unit draft is defined as the draft per unit width of the worked soil (width of tillage). Vertical specific draft is defined as the draft per unit area of vertical cut (vertical cross sectional area of worked soil). (Al-Suhaibani and Ghaly, 2010). The cross sectional area of the worked soil was obtained by multiplying the tillage depth by the width of tillage. The portions of the vertical specific draft used for cutting and moving the soil particles (pulverization) were also determined.

The horizontal specific draft is defined as the draft divided by horizontal tilled area per unit time (Al-Suhaibani and Ghaly, 2010). The horizontal tilled area per unit time (s) was obtained by multiplying the implement travel speed by the width of tillage.

The coefficient of pull is the draft per the product of weight of implement and the weight of worked soil. The weight of worked soil was obtained by multiplying the soil bulk density by the volume of the worked soil. The volume of the worked soil was determined by multiplying the tillage depth by the width of tillage and the implement travel speed.

2.7 Data analysis

The data obtained were analyzed using Statistical Package for Social Sciences (SPSS) software (version 17.0, 2008) with Randomized Complete Block Design

(RCBD) program.

3 Results and discussion

3.1 Soil analysis test for the location

Analysis of soil test was carried out at the study location for the tillage implement. The results of the analysis test of the soil are presented in Table 2.

Table 2 Soil test analysis at Mbiabong for the tillage implement

Soil Parameter	Values
	Spring Tine Cultivator
Soil Composition	(%)
Sand	69.8
Silt	3.9
Clay	26.3
Classification	Sandy loam
Average Bulk density at depth of:	(gcm^{-1})
0 – 30 cm	1.30
Average Moisture content at depth of:	(%)
0 – 30 cm	15.87

3.2 Experimental test results

The average time taken for the tractor to pull the implement across a distance of 100 m at different tillage depths and tractor speeds during the experimental runs at the study location is presented in Table 3.

Table 3 Field experimental test results

Tillage depth (cm)	Tractor speed ($kmhr^{-1}$)	Distance covered (m)	Average time taken(s)
	3.6	100	135.13
10	5.4	100	80.64
	7.2	100	56.81
	9.0	100	42.01
	10.8	100	38.46
	3.6	100	135.10
	5.4	100	80.60
	7.2	100	54.75
20	9.0	100	42.05
	10.8	100	38.45
	3.6	100	135.15
	5.4	100	80.55
	7.2	100	56.85
30	9.0	100	42.05
	10.8	100	38.55

3.3 Width of cut and pulverization

The overall width of tillage was 240 cm. The overall width of cut (66 cm) was calculated by multiplying the width of tine (6 cm) by the number of tines (11). The remaining part of the width of tillage (174 cm) was taken to be the width of pulverization. Therefore, the percentage width of cut was obtained to be 27 5 % while that of pulverization was 72.5 %.

3.4 Influence of implement speed and tillage depth on draft force

The force needed to work, that is, cut and move the soil varied with both the tillage depth and the implement speed as illustrated in Figure 6. From this figure, it was observed that draft force increased with increase in tillage depth and implement speed. This could be because at higher tillage depth and implement speed, tractor requires more force to overcome the soil resistance in order to achieve tillage. The increase in draft force with tillage depth or the implement speed appears to be linear as indicated in Table 4. For all tillage depths, the observed increase in draft force when the implement speed was 1.24-1.76 ms^{-1} was greater than the observed draft force when the implement speed was 0.74-1.24 ms^{-1}.

Table 4 The incremental increase in draft with increases in implement speed at different tillage depths

Tillage depth (cm)	Implement speed interval (ms^{-1})	Increase in draft force ($kNmsec^{-1}$)
	0.74-1.24	0.010
10	1.24-1.76	0.023
	1.76-2.38	0.025
	2.38-2.60	0.027
	0.74-1.24	0.022
20	1.24-1.76	0.035
	1.76-2.38	0.048
	2.38-2.60	0.055
	0.74-1.24	0.036
30	1.24-1.76	0.054
	1.76-2.38	0.074
	2.38-2.60	0.091

Table 5 The incremental increase in draft with increases in tillage depth at different implement speeds

Implement speed (ms^{-1})	Tillage depth intervals (cm)	Increase in draft force (kNm^{-1})
0.74	10-20	1.39
	20-30	1.87
1.24	10-20	1.45
	20-30	1.94
1.76	10-20	1.51
	20-30	2.04
2.38	10-20	1.70
	20-30	2.20
2.60	10-20	1.76
	20-30	2.28

Also, the observed draft force when the implement speed was 1.76-2.38 was greater than the observed draft force when the implement speed was 1.24-1.76 ms^{-1}. Lastly, the observed draft force when the implement speed was 2.38-2.60 ms^{-1} was greater than the observed draft force when the implement speed was 1.76-2.38 ms^{-1}. It was, also seen that for all implement speeds, the increase in draft force when the tillage depth was increased from 20-30 cm was more than the increase in the draft force when the tillage depth was increased from 10-20 cm as shown in Table 5. These findings agreed with the reports presented by Al-Janobi and Al-Suhaibani (1998) and Taniguchi et al. (1999) but disagreed with the results presented by Al- Sahaibani and Ghaly (2010).

Increasing the implement speed from 0.74-2.60 ms^{-1} (251.3 %) increased the draft force by 170.0%, 150.0% and 152.7 % for the tillage depths of 10, 20 and 30 cm, respectively. On the other hand, increasing the tillage depth from 10-30 cm (200 %) increased the draft force by 43.5%, 33.7%, 35.0%. 29.4% and 29.5 % for the implement speeds of 0.74, 1.24, 1.76, 2.38 and 2.60 ms^{-1}, respectively. These results indicate that tillage depth had greater influence on draft force than implement speed. These results are in agreement with the earlier reports presented by Mamman and Oni (2005) and Al- Sahaibani and Ghaly (2010).

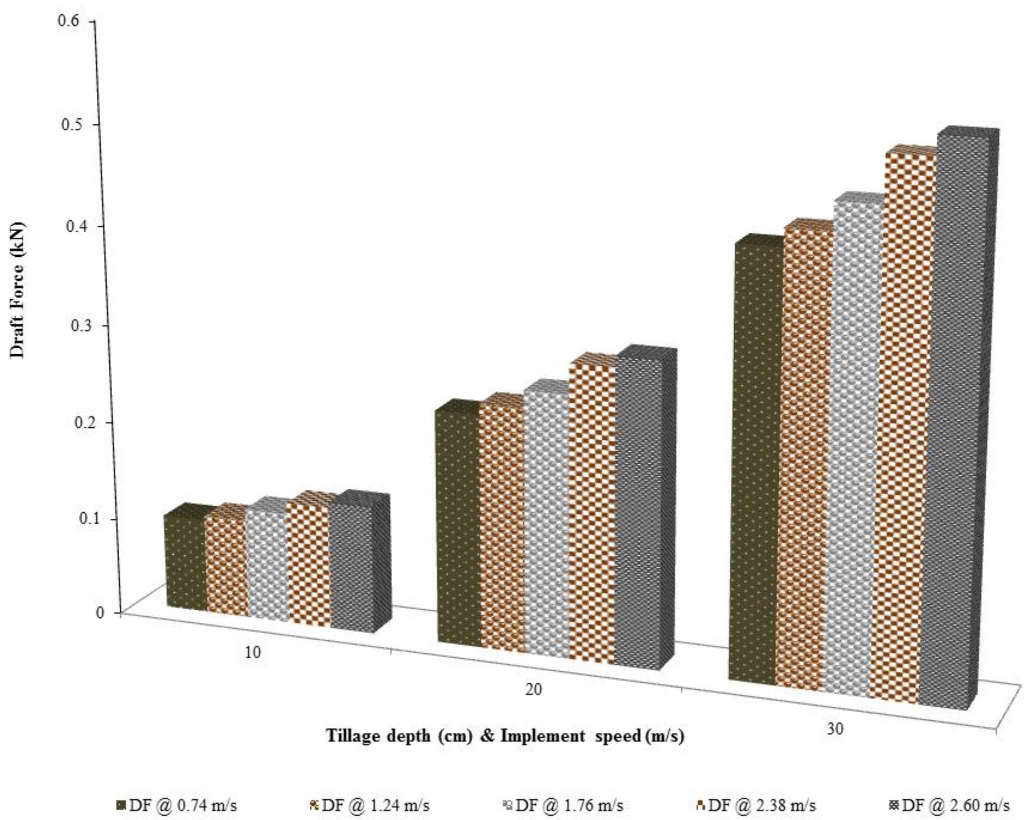

Figure 6 Effects of Tillage Depth and Implement Speed on Draft Force

3.5 Influence of implement speed and tillage depth on unit draft

The results of the influence of implement speed and tillage depth on unit draft followed the same trend as the draft as indicated in Figure 7. The reason for this trend is same as given for the draft force. The increase in unit draft with the tillage depth and the implement speed also seem to be linear as shown in Table 6. For all tillage depths, the observed increase in unit draft when the implement speed was 1.24-1.76 ms^{-1} was greater than the observed unit draft when the implement speed was 0.74-1.24 ms^{-1}. Again, the observed unit draft when the implement speed was 1.76-2.38 ms^{-1} was more than the unit draft when the implement speed was 1.24-1.76 ms^{-1}.

In the same vain, the unit draft when the implement speed was 2.38-2.60 ms^{-1} was greater than the unit draft when the implement speed was 1.76-2.38 ms^{-1}. Also, it was seen that for all implement speeds, the increase in unit draft when the tillage depth was increased from 20-30 cm was greater than the unit draft when the tillage depth was increased from 10-20 cm as indicated in Table 7.

Table 6 The incremental increase in unit draft with increases in implement speed at different tillage depths

Tillage depth (cm)	Implement speed interval (ms^{-1})	Increase in unit draft (kNm^{-1}msec^{-2})
10	0.74-1.24	0.006
	1.24-1.76	0.007
	1.76-2.38	0.008
	2.38-2.60	0.013
20	0.74-1.24	0.006
	1.24-1.76	0.013
	1.76-2.38	0.021
	2.38-2.60	0.032
30	0.74-1.24	0.008
	1.24-1.76	0.031
	1.76-2.38	0.024
	2.38-2.60	0.227

Increasing the implement speed from 0.74-2.60 ms^{-1}(251.3 %) increased the unit draft by 116.6%, 433.3% and 2737.5 % for the tillage depths of 10, 20 and 30 cm, respectively. On the other hand, increasing the tillage depth from 10-30 cm (200 %) increased the unit draft by 33.3, 35.0%, 42.8%, 28.5% and 80.0 % for the implement speeds of 0.74, 1.24, 1.76, 2.38 and 2.60 ms^{-1}, respectively. These results also indicate that the tillage depth had greater influence on the unit draft than the implement speed. The results are in conformity with the earlier research work presented by Mamman and Oni (2005) and Al- Sahaibani and Ghaly (2010).

Table 7 The incremental increase in unit draft with increases in tillage depth at different implement speeds

Implement speed (ms^{-1})	Tillage depth intervals (cm)	Increase in unit draft(kNm^{-1}m^{-2})
0.74	10-20	0.60
	20-30	0.80
1.24	10-20	0.60
	20-30	0.81
1.76	10-20	0.63
	20-30	0.90
2.38	10-20	0.71
	20-30	0.92
2.60	10-20	0.75
	20-30	1.35

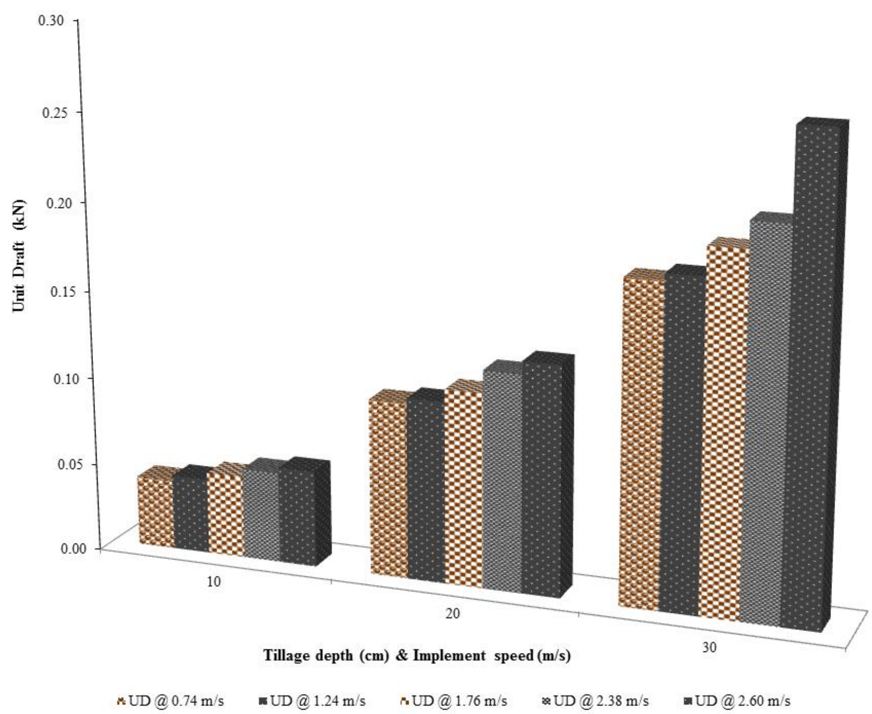

Figure 7 Effects of Tillage Depth and Implement Speed on Unit Draft

3.6 Influence of implement speed and tillage depth on vertical specific draft

The results illustrated in Figure 8 indicate that increasing the tillage depth or the implement speed increased the vertical specific draft. This shows that the more the tillage depth and implement speed, the more vertical specific draft is required. This follows the same trend as the draft force and the unit draft. The reason for the trend is same as given for the two parameters above.

Table 8 The incremental increase in vertical specific draft with increases in implement speed at different tillage depths

Tillage depth (cm)	Implement speed interval (ms^{-1})	Increase in vertical specific draft ($kNm^{-2}msec^{-1}$)
10	0.74-1.24	0.06
	1.24-1.76	0.09
	1.76-2.38	0.06
	2.38-2.60	0.14
20	0.74-1.24	0.02
	1.24-1.76	0.07
	1.76-2.38	0.09
	2.38-2.60	0.14
30	0.74-1.24	0.04
	1.24-1.76	0.07
	1.76-2.38	0.11
	2.38-2.60	0.09

Table 9 The incremental increase in vertical specific draft with increases in tillage depth at different implement speeds

Implement speed(ms^{-1})	Tillage depth intervals(cm)	Increase in vertical specific draft($kNm^{-2}m^{-1}$)
0.74	10-20	0.5
	20-30	1.0
1.24	10-20	0.8
	20-30	1.0
1.76	10-20	0.7
	20-30	1.0
2.38	10-20	0.9
	20-30	1.1
2.60	10-20	1.0
	20-30	1.1

Table 8 shows that increasing the implement speed from 0.74-2.60 ms^{-1} (251.3 %) increased the vertical specific draft by 133.3%, 600.0% and 125.0 % for the tillage depths of 10, 20 and 30 cm, respectively. On the

other hand, Table 9 indicates that increasing the tillage depth from 10-30 cm (200 %) increased the vertical specific draft by 100.0%, 25.0%, 42.8%, 22.2% and 10.0 % for the implement speeds of 0.74, 1.24, 1.76, 2.38 and 2.60 ms^{-1}, respectively.

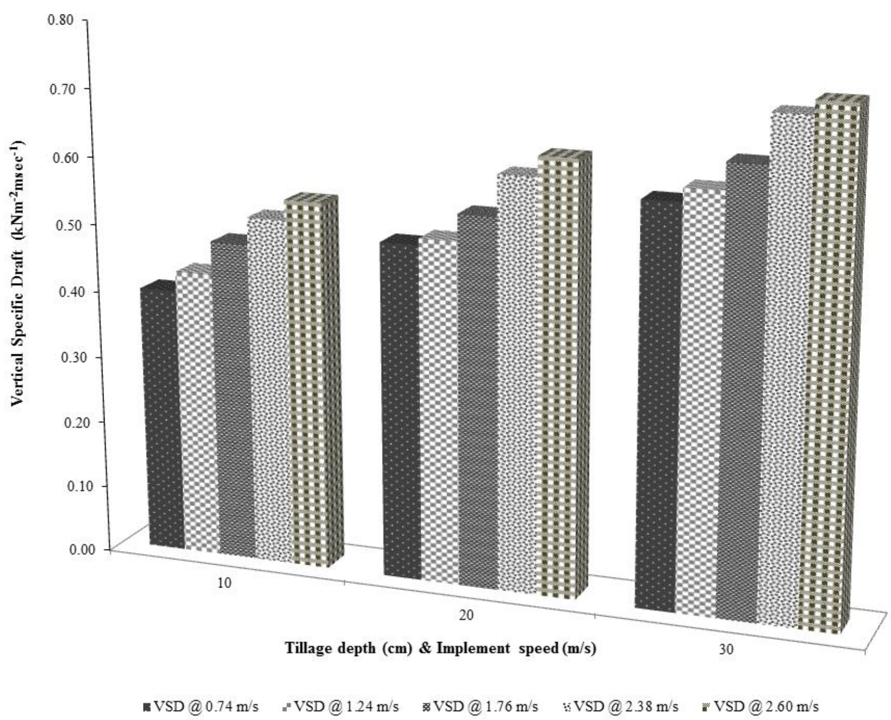

Figure 8 Effects of Tillage Depth and Implement Speed on Vertical Specific Draft

3.7 Influence of implement speed and tillage depth on horizontal specific draft

The results as presented in Figure 9 indicate that increasing the tillage depth increased the horizontal specific draft but increasing the implement speed decreased the horizontal specific draft. This could be because horizontal specific draft is the draft divided by the horizontal tilled area per unit time.

Table 10 The incremental increase in horizontal specific draft with increases in implement speed at different tillage depths

Tillage depth (cm)	Implement speed interval (ms^{-1})	Increase in horizontal specific draft ($kNm^{-2}msec^{-1}$)
10	0.74-1.24	-0.040
	1.24-1.76	-0.019
	1.76-2.38	-0.016
	2.38-2.60	-0.045
20	0.74-1.24	-0.100
	1.24-1.76	-0.038
	1.76-2.38	-0.016
	2.38-2.60	-0-0.18
30	0.74-1.24	-0.076
	1.24-1.76	-0.032
	1.76-2.38	-0.045
	2.38-2.60	-0.040

It has been stated that the horizontal tilled area per unit time was calculated by multiplying the implement speed by the width of tillage. The width of tillage in this instance is constant. The only variable in the denominator is the implement speed. Therefore the higher the implement speed, the less is the horizontal specific draft as seen Figure 9. Table 10 indicates that increasing the implement speed from 0.74-2.60 ms^{-1} (251.3 %) reduced the horizontal specific draft by 12.5%, 122.2%, and 300.0 % for the tillage depths of 10, 20 and 30 cm, respectively. On the other hand, Table 11 shows that increasing the tillage depth from 10-30 cm (200 %) increased the horizontal specific draft by 37.5%, 40.0%, 66.6%, 33.3% and 33.3 % for the implement speeds of 0.74, 1.24, 1.76, 2.38 and 2.60 ms^{-1}, respectively. The results are in agreement with the results presented by Al-Sahaibani and Ghaly (2010).

Table 11 The incremental increase in horizontal specific draft with increases in tillage depth at different implement speeds

Implement speed(ms^{-1})	Tillage depth intervals (cm)	Increase in horizontal specific draft ($kNm^{-2}m^{-1}$)
0.74	10-20	0.8
	20-30	1.1
1.24	10-20	0.3
	20-30	0.5
1.76	10-20	0.3
	20-30	0.4
2.38	10-20	0.3
	20-30	0.4
2.60	10-20	0.8
	20-30	1.1

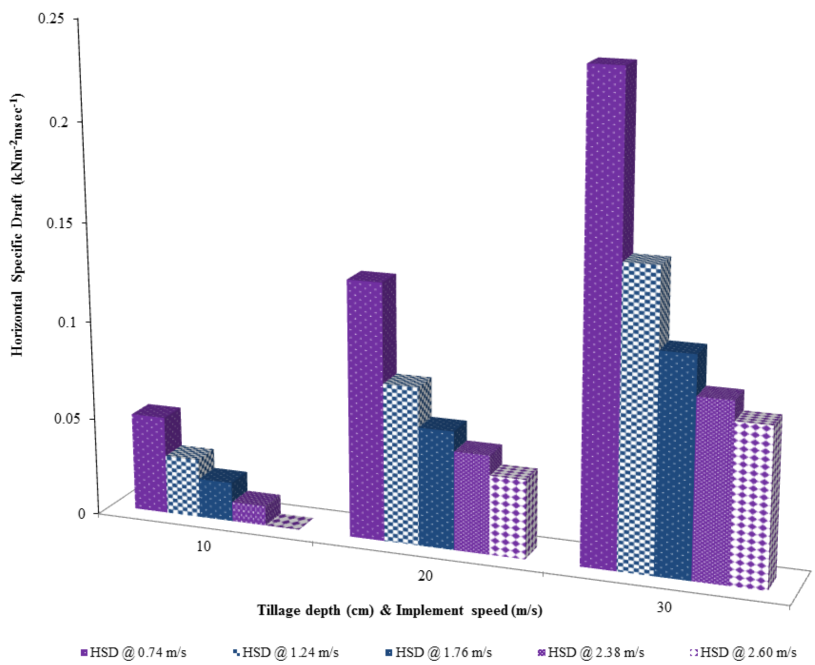

Figure 9 Effects of Tillage Depth and Implement Speed on Horizontal Specific Draft

3.8 Influence of implement speed and tillage depth on the coefficient of pull

The results as illustrated in Figure 10 show that increasing the tillage depth increased the coefficient of pull but increasing the implement speed decreased the coefficient of pull. Coefficient of pull is the draft per the product of weight of implement, soil bulk density, depth of tillage, width of tillage and the implement speed. The weight of implement, soil bulk density, width of tillage are completely constants. From the experimental test results, the tillage depth is partially constant. Therefore the only completely variable in the denominator for obtaining the coefficient of pull is the implement speed. Hence the higher the implement speed the less is the coefficient of pull as observed in Figure 10. Table 12 shows that increasing the implement speed from 0.74-2.60 ms^{-1} (251.3 %) reduced the coefficient of pull by 100.0%, 350.0% and 600.0 % for the tillage depths of 10, 20 and 30 cm, respectively. In another way, Table 13 indicates that increasing the tillage depth from 10-30 cm (200 %) increased the coefficient of pull by 8.3%, 33.3%, 20.0%, 25.0% and 25.0 % for implement speeds of 0.74, 1.24, 1.76, 2.38 and 2.60 ms^{-1}, respectively.

Table 12 The incremental increase in coefficient of pull with increases in implement speed at different tillage depths

Tillage depth (cm)	Implement speed interval (ms^{-1})	Increase in coefficient of pull ($kNkN^{-1}msec^{-1}$)
10	0.74-1.24	-0.008
	1.24-1.76	-0.003
	1.76-2.38	-0.001
	2.38-2.60	-0.004
20	0.74-1.24	-0.018
	1.24-1.76	-0.007
	1.76-2.38	-0.004
	2.38-2.60	-0.004
30	0.74-1.24	-0.028
	1.24-1.76	-0.011
	1.76-2.38	-0.006
	2.38-2.60	-0.004

Table 13 The incremental increase in coefficient of pull with increases in tillage depth at different implement speeds

Implement speed(ms^{-1})	Tillage depth intervals (cm)	Increase in coefficient of pull ($kNkN^{-1}msec^{-1}$)
0.74	10-20	0.13
	20-30	0.12
1.24	10-20	0.08
	20-30	0.06
1.76	10-20	0.06
	20-30	0.05
2.38	10-20	0.04
	20-30	0.05
2.60	10-20	0.04
	20-30	0.05

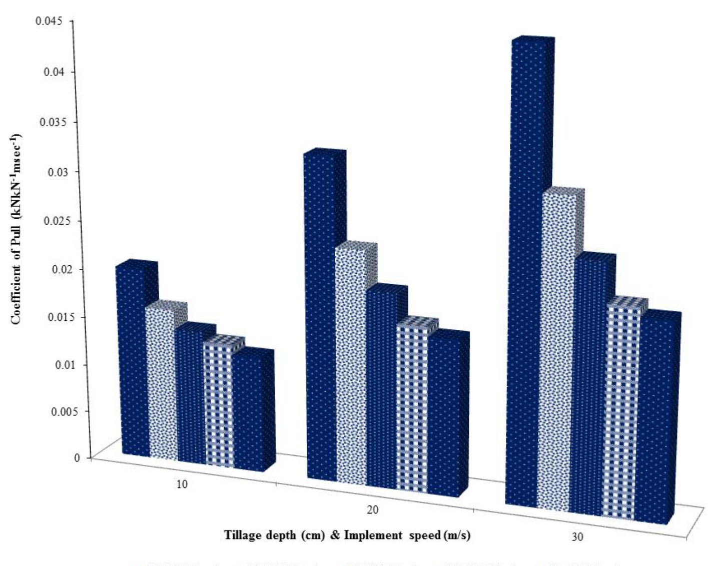

Figure 10 Effects of Tillage Depth and Implement Speed on Coefficient of Pull

4 Conclusion

The field for the experiment was sandy loam soil with the composition of 3.9 % silt, 69.8 % sand and 26.3 % clay. Therefore, sandy loam soil with 69.8 % sand is recommended.

The influences of tillage depths and implement speeds on draft, unit draft, vertical specific draft, horizontal specific draft and coefficient of pull were accessed. The results showed that increasing the tillage depth and implement speed increased the draft, unit draft and vertical specific draft. It was established that the relationship between them is linear. Increasing the tillage depth increased the horizontal specific draft and the coefficient of pull but increasing the implement speed decreased the horizontal specific draft and the coefficient of pull.

Approximately 27.5 % of the draft was focused towards cutting the soil and 72.5 % was spent in pulverization of the soil clods. The values of the vertical specific draft were much greater than those of the horizontal specific draft for all tillage depths and implement speeds. The tillage depth had greater effect on the draft, unit draft, specific draft and coefficient of pull than the implement speed. In view of this, attention should be given to the root zone of the crop to be planted for which tillage is made.

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