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Determination of Kinetic Parameters of a Super Heavy Chisel Plow Under Various Operating Conditions

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Abstract: Problem statement: Tillage is a process of creating a desirable soil condition for seed germination and growth. The tillage of soil is considered to be one of the biggest farm operations as the tillage operation requires the most energy on the farm. Chisel plow is widely used by farmers as a primary tillage tool. Performance data for chisel plow operation is essential in order to reduce the cost of tillage operation. **Approach:** Field experiments were conducted using a fully instrumented MS 3090 tractor to measure the draft of a super heavy chisel plow in a sandy soil over wide ranges of plowing depths and forward speeds. The data were measured and recorded using an instrumentation system and data logger. **Results:** The effects of plowing depth and forward speeds on draft, unit draft, vertical specific draft, horizontal specific draft and coefficient of pull were evaluated. The results indicated that increasing the plowing depth and/or the forward speed increased the draft, unit draft and vertical specific draft. Also, increasing the plowing depth increased the horizontal specific draft and the coefficient of pull, while increasing the forward speed decreased the horizontal specific draft and the coefficient of pull. **Conclusion:** About 21.8% of the draft force was directed towards cutting the soil and 78.2% was consumed in pulverization of soil particles. The values of the vertical specific draft were much higher than those of the horizontal specific draft for all plowing depths and forward speeds. The plowing depth had more pronounced effect on the draft, unit draft, specific draft and coefficient of pull than the forward speed. The optimum forward speed was 1.75 m sec^{-1}. The recommended plowing depth should be based on the type of crop (depth of the root system).

Key words: Tillage, draft, unit draft, specific draft, coefficient of pull, sandy soil, instrumentation, chisel plow

INTRODUCTION

Tillage as a farm operation aims at creating a desired final soil condition for seeds from some undesirable initial soil condition through manipulation of soil with the aim of increasing crop yield (Gil and Vanden Berg, 1968; Al-Suhaibani and Ghaly, 2010). There are two types of tillage: primary and secondary. Primary tillage loosen the soil and mix fertilizer and plant residues resulting in a rough soil texture. Secondary tillage produces much finer soil and sometimes shapes the rows (ASAE, 2004). Troeh *et al*. (1991) reported three reasons for tillage: (a) incorporation of plant residues and fertilizer, (b) seedbed preparation, (c) weed control and (d) soil and water conservation.

Several tillage implements are used by farmers including: chisel plow. Disc plow, moldboard plow, disc harrows, rotating tillers and bed forming tillers. However, the selection of tillage implements for seedbed preparation and weed control depends on soil type and condition, type of crop, previous soil treatments, crop residues and weed type (Troeh *et al*., 1991). One of the tillage implements widely used by farmers is the chisel plow which is considered to be a primary tillage implement because it is mainly used for the initial soil working operations (Srivastava, 1993).

The ability of tillage implements to maintain surface residue coverage is largely dependent on the main active component of implement. Raper (2002) compared two categories of tillage implements to determine their ability to maintain grain sorghum surface residue coverage when operating at two different tillage depths for fall and spring tillage. Chisel-type implements were found to bury substantially less crop residue than disk-type implements. Disk-type implements were found to bury increased amounts of crop residue when operating at deeper tillage depths.

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The tillage of soil is considered to be one of the biggest farm operations and it requires the most energy and power spent on farms (Finner and Straub, 1985; Abbaspour-Gilandeh *et al*., 2006; Al-Suhaibani and Ghaly, 2010). Therefore, draft and power requirements are important in order to determine the size of the tractor that could be used for a specific implement. The draft required for a given implement will also be affected by the soil conditions and the geometry of the tillage implement (Taniguchi *et al*., 1999; Naderloo *et al*., 2009; Olatunji and Davies, 2009; Sahu and Raheman, 2006) as well as the plowing depth and forward speed (Van Muysen *et al*., 2000; Al-Suhaibani and Ghaly, 2010; Al-Suhaibani *et al*., 2010).

Owen (1989) studied the force-depth relationship of a chisel plow tine with three different wing types in a compacted clay loam soil and found the vertical force on the tine to increase linearly with the operating depth while the horizontal force, moment and total force to increase quadratically with operating depth. He also noticed that the wing width had a significant effect on the vertical force and no interaction existed between the wing width and the depth.

Al-Suhaibani *et al*. (2010) studied the relationship between draft and forward speed and tillage depth for several chisel plows and found the tillage depth to have more effect on the draft than the forward speed. The relationship between depth of cut and the increase in the weight of disc plow and the draft was investigated by Olatunji and Davies (2009). The model derived from the field study showed that the draft for disc plow increase with speed and soil moisture content and the depth of cut varied with changes in the weight of the implement.

The specific draft (force per cross sectional area of worked soil), energy use for moldboard plow, chisel plow and disc harrow at different soil conditions were investigated by Arvidsson *et al*. (2004). They found that the specific draft was generally the highest for the chisel plow and the lowest for the moldboard plow and the disc harrow and referred that to the differences in implement geometry and mode of soil break-up.

Al-Suhaibani and Ghaly (2010) reported the higher values for vertical specific drafts than horizontal specific draft. They also found the vertical specific draft to increase with increases in tillage depth while the horizontal specific draft to increase with increase in the tillage depth and to decrease with the increases in the forward speed. Gill and Vanden Berg (1968) stated that the efficiency and economy of the tillage operation could be evaluated from the mechanics of tillage tools/soil interaction which would provide a method by position of the three-point linkage, (e) a data logger, to monitor and record data from various parameters and (f) a computer, for processing and analyzing data. Which the performance of the tillage implements could be predicted and controlled by the design of a tillage tool or by the use of a sequence of tillage tools. In studying the strength and forces for the chisel plow, Brown *et al*. (1989) evaluated the stress on the chisel plow using the finite element analysis and reduced the weight by 23% without causing excessive stress on the plow. Brown *et al*. (1989) stated that manufacturers of tillage implements tend to overdesign their products due to a lack of the proper design and analysis of tools and the technical expertise required to optimize the strength of an implement.

The main objectives of this study was to evaluate the performance of a super heavy duty 680 Kg (6.67 KN) chisel plow with 15 fully curved shanks distributed in two rows in a sandy soil. The specific objectives were to study the effects of plowing depth and forward speed on: (a) draft, (b) unit draft, (c) specific draft and coefficient of pull.

MTERIALS AND METHODS

Fully instrumented tractors: A fully instrumented Massy Ferguson (MF) 3090 tractor (Fig. 1) was used in the study. The specifications of the tractor are presented in Table 1. The instrumentation system consisted of: (a) a drawbar dynamometer, to measure drawbar pull (b) two wheel torque transducers, to measure wheel forces (c) a three-point linkage-implement force and depth transducer, to measure the three-point linkage forces and depth, (d) other transducers, to monitor ground speed, fluid temperatures (engine oil, transmission oil, front axle oil, engine coolant and engine fuel), Power Take Off (PTO) torque, right and left position of front wheel steering and angular position and indication of the lifting.

Fig. 1: The fully instrumented tractor

Table 1: Tractor specifications

Parameter	Value
Power	75 Kw (100 HP)
Weight	47.35 kN
Weight on front wheels	18.50 kN
Weight on rear wheels	28.85 kN
Distance between front and rear wheels	269.90 cm
Distance between front wheels	187.00 cm
Distance between rear wheels	163.00 cm
Front wheels size	31.60 R 28
Rear wheels size	18.40 R 38
Height of drawbar	58.30 cm
Height of center of gravity	174.00 cm

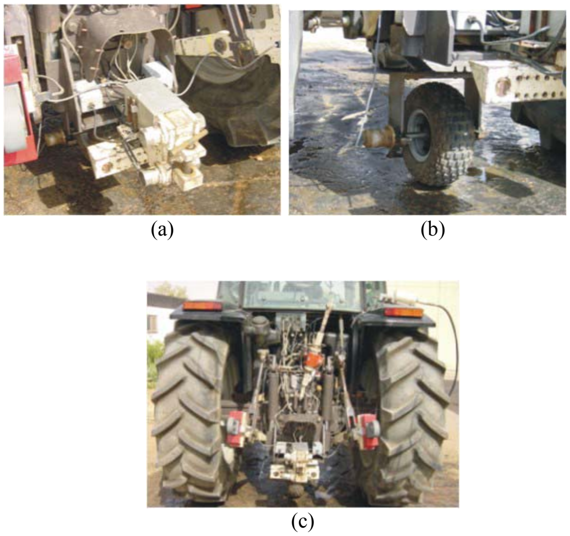


Fig. 2: Draft, speed and depth measuring devices

Figure 2 shows the draft, forward speed and depth measuring devices of the instrumentation system. The draft was measured using a drawbar dynamometer consisting of two load sensing clevis bolts and the force exerted by the plow was measured by a strain gauge bridge within the clevis bolts. The tractor ground speed was measured using a fifth wheel attached to a suitable position underneath the tractor. An RS shaft encoder (360 pulses/revolution) was mounted on the fifth wheel and used to measure the distance traveled and hence the actual ground speed. The depth was measured using the three point linkage-implement force and depth transducer which was developed specifically for use with mounted implement of categories II (40-100 hp) and III (80-225 hp) as specified by the ASAE standard (ASAE, 1985). More detailed information about the other componentry instrumentation system are provided in Al-Suhaibani *et al*. (2010)

A data logger mounted on a platform to the left of the tractor operator was used to scan and record the output signals from the transducers. The strain gauge transducers in the instrumentation system were connected to the data logger through amplifier boxes, which also provided a regulated power supply to give excitation to the transducer. The activity unit was used to provide excitation to both the data logger and transducers with input supply from the tractor battery (12 V). It was, also, used to indicate the activity performed during field tests. Owen (1989) found the vertical force to increase linearly with the plowing depth while the horizontal force to increase quadratically with the plowing depth.

Fig. 3: A super heavy chisel plow

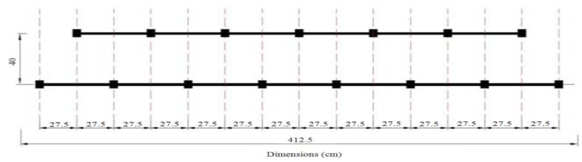


Fig. 4: Distribution of shanks on the plow frame. Plow width = 385 cm; Width of plowed strip = 412.5 cm; Distance between the paths of shanks = 27.5 cm

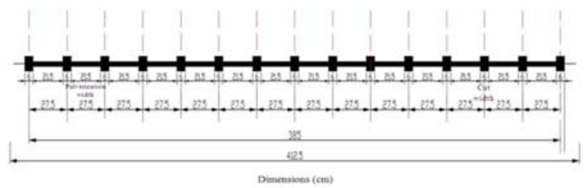
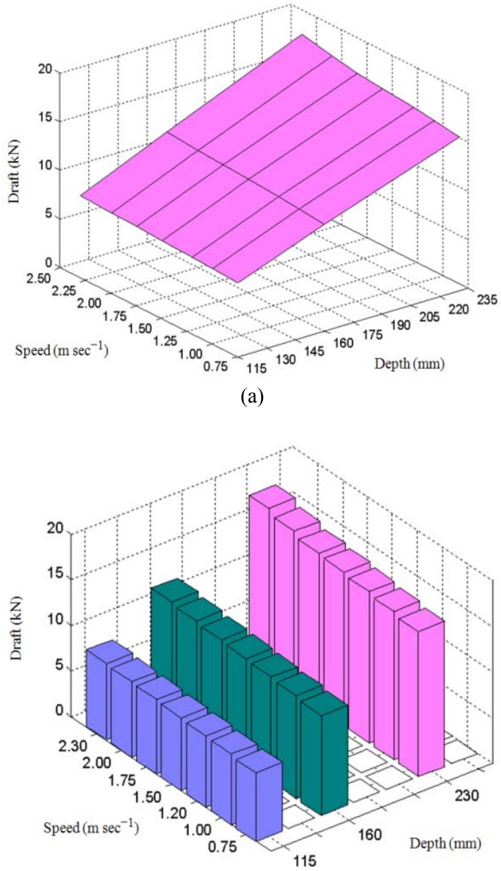


Fig. 5: Distance between the paths of shanks. Total width of tillage = 412.5 cm; Number of shanks = 15; Width of chisel tool = 6 cm; Total width cut = 90 cm; % of cut = 21.8%; Width of pulverization = 322.5 cm; % of pulverization = 78.2%

Chisel plow: The super heavy chisel plow (Model STT-15, Serial No. G99-343499) GALUCHO Company, Portugal was used in the study (Fig. 3). The plow (Fig. 5) weighed 680 Kg (6.67 kN) and had a width of 385 cm and 15 shanks distributed in 2 rows. The specifications of the plow are shown in Table 2. Figure 4 shows the distribution of shanks on plow frame while Fig. 6 shows the distance between the paths of shanks and the width of worked soil (plowed strip).

Field experiments: Experiments were conducted using the fully instrumented MF 3090 tractor to measure the draft requirement of a heavy duty chisel plow in a sandy loam soil over wide ranges of speeds and depths at the Agricultural Research and Experimental Farm of the King Saud University in Dirab. Four speeds and three depths were tested as shown in Table 3. This resulted in 12 treatment combinations. Ten measurements were taken for each treatment combinations at 5 min intervals.



(a)

(b)

Fig. 6: Effects of plowing depth and forward speed on the measured draft

Table 2: Specifications of super heavy chisel plow

Parameter	Volume
Type of plow	Super heavy duty
Model	STT-15 (Serial No. G99-343499)
Manufacture	GALUCHO Company Portugal
Total weight	680 Kg (6.67 kN)
Total width of plow	385 cm
Number of shanks	15
Width of shank	5 cm
Thickness of shank	2.5 cm
Shank stem angle	42°
Number of rows	2
Number of shanks in first row	7
Distance between shanks in first row	55 cm
Number of shanks in second row	8
Distance between shanks in second row	55 cm
Width of chisel tool	6 cm

Table 3: Experimental parameters

Parameter	Values
Depth (mm)	115, 160, 230
Speed (m sec^{-1})	0.75, 1.20, 1.75, 2.30

The data logger monitored and recorded the data for depth, speed and draft during the field experiment. The laptop displayed the values of the measured parameters and analyzed the data.

RESULTS

The width of the plow was 385 cm and the total width of plowed strip was 412.5 cm. The total width of cut (90 cm) was calculated by multiplying the width of the cutting tool (6 cm) by the number of shanks (15). The remaining part of the width of plowed strip (322.5 cm) was considered to be the width of pulverization. Accordingly, the plow shanks were able to cut 21.8% of the total plowed width and the movement of the soil (pulverization) resulted in the breakage of soil particles and preparation of the seedbed.

Table 4 shows the measured draft force (kN) and the calculated unit draft (kN m^{-1}) at various plowing depths and forward speeds. The unit draft is defined in this study as the draft per unit width of the worked soil (width of plowed strip).

Table 4: Draft and unit draft

Depth (mm)	Speed (m sec^{-1})	Draft (kN)	Unit Draft (kN m^{-1})
115	0.75	7.52 (0.593)	1.83
	1.20	7.86 (0.285)	1.91
	1.75	8.13 (0.112)	1.97
	2.30	8.41 (0.673)	2.04
160	0.75	11.00 (0.717)	2.67
	1.20	11.49 (0.421)	2.79
	1.75	11.84 (0.513)	2.87
	2.30	12.34 (0.597)	2.99
230	0.75	15.90 (0.841)	3.85
	1.20	16.58 (0.652)	4.02
	1.75	17.13 (0.579)	4.15
	2.30	18.31 (0.979)	4.44

( ) The values in brackets represent standard deviation; Plow width = 385 cm; Width of plowed strip = 412.5 cm; Unit draft = Draft/width of plowed strip

Table 5: Vertical specific draft

Depth (mm)	Speed (m sec^{-1})	Draft (kN)	Vertical specific draft (kN m^{-2}) Total	Cutting	Pulverization
115	0.75	7.52	15.85	3.46	12.40
	1.20	7.86	16.57	3.61	12.96
	1.75	8.13	17.14	3.74	13.40
	2.30	8.41	17.73	3.87	13.87
160	0.75	11.00	16.67	3.63	13.04
	1.20	11.49	17.41	3.80	13.62
	1.75	11.84	17.94	3.91	14.03
	2.30	12.34	18.70	4.08	14.62
230	0.75	15.90	16.76	3.65	13.10
	1.20	16.58	17.48	3.81	13.67
	1.75	17.13	18.06	3.94	14.12
	2.30	18.31	19.30	4.21	15.09

Vertical tilled area = Depth of tillage × width of plowed strip; For a depth of 115 mm = 0.115×4.125 = 0.4743 m^2; For a depth of 160 mm = 0.160 × 4.125= 0.660 m^2; For a depth of 230 mm = 0.230×4.125 = 0.948 m^2; % Width of plow strip = 21.8%

Table 5 shows the calculated vertical specific draft (kN m^{-2}) which is defined in this study as the draft per projected unit area of tillage (cross sectional area of worked soil). The cross sectional area of the worked soil was calculated by multiplying the plowing depth of tillage by the width of plowed strip. The portions of specific draft used for cutting the soil and moving the soil particles (pulverization) were also calculated as shown in Table 5.

Table 6 shows the calculated horizontal specific draft. The horizontal specific draft is defined in this study as the draft divided by horizontal plowed area per unit second. The horizontal plowed area per second was calculated by multiplying the forward speed by the width of plowed strip. The results of the vertical specific draft are shown in Table 6.

Table 7 shows the total weight of the plow and the worked soil (cut/moved) by the plow) at various plowing depths and forward speeds. The weight of worked soil was calculated from the volume of soil created by the plowing depth and the forward movement of the plow in a second and the width of plowed strip. The coefficient of pull (kN kN^{-1}) was calculated by dividing the draft by the total weight of plow and the worked soil. The results are also presented in Table 7.

Table 6: Horizontal specific draft

Depth (mm)	Speed (m sec^{-1})	Draft (kN)	Horizontal specific draft (kN m^{-2}) Total	Cutting	Pulverization
115	0.75	7.52	2.43	0.53	1.90
	1.20	7.86	1.59	0.35	1.24
	1.75	8.13	1.13	0.25	0.88
	2.30	8.41	0.89	0.19	0.69
160	0.75	11.00	3.56	0.78	2.78
	1.20	11.49	2.32	0.51	1.81
	1.75	11.84	1.64	0.36	1.29
	2.30	12.34	1.30	0.28	1.02
230	0.75	15.90	5.14	1.12	4.02
	1.20	16.58	3.35	0.73	2.62
	1.75	17.13	2.37	0.52	1.85
	2.30	18.31	1.93	0.42	1.51

Horizontal tilled area = Width of plowed strip × forward speed; % Width of cut = 21.8%

Table 7: Coefficient of pull

Depth (mm)	Speed (m sec^{-1})	Draft (kN)	Volume of worked soil (m^3)	Weigh of plow and Worked soil (kN)	Coefficient of pull (kN kN^{-1})
115	0.75	7.52	0.36	11.38	0.66
	1.20	7.86	0.57	14.21	0.55
	1.75	8.13	0.83	17.66	0.46
	2.30	8.41	1.09	21.12	0.40
160	0.75	11.00	0.50	13.23	0.83
	1.20	11.49	0.79	17.16	0.67
	1.75	11.84	1.16	21.97	0.54
	2.30	12.34	1.52	26.77	0.46
230	0.75	15.90	0.71	16.09	0.99
	1.20	16.58	1.14	21.75	0.76
	1.75	17.13	1.66	28.66	0.60
	2.30	18.31	2.18	35.57	0.51

Plow weight = 680 kg = 6.67 kN; Volume of worked soil = Plowed depth × width of plowed strip × forward speed; Soil density = 1350 kg m^{-3} = 13.24 kN m^{-3}

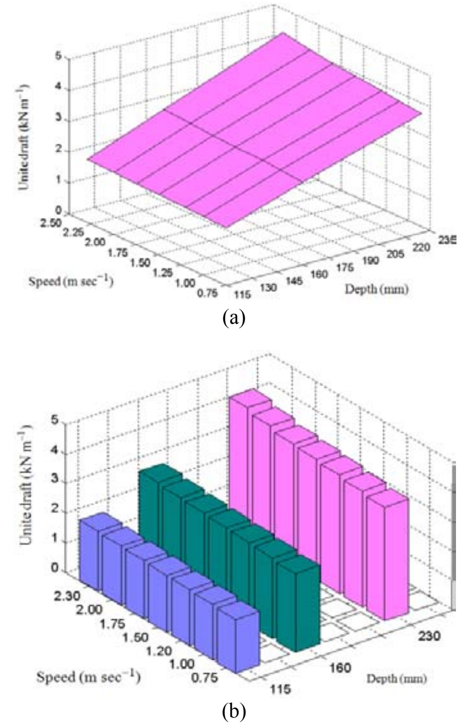


Fig. 7: Effects of plowing depth and forward speed on the unit draft

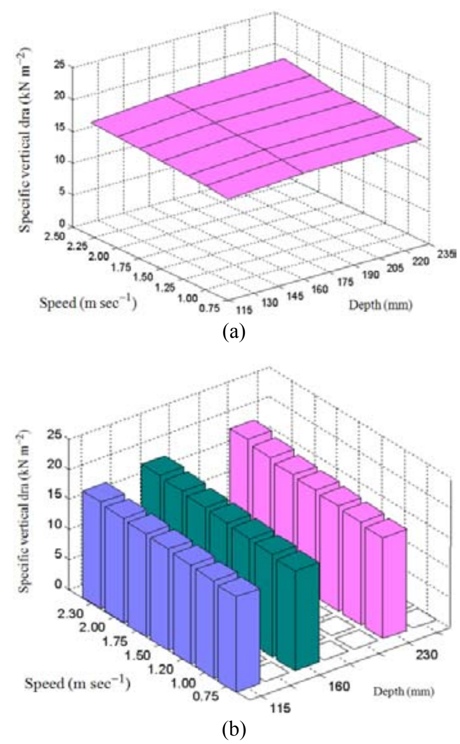
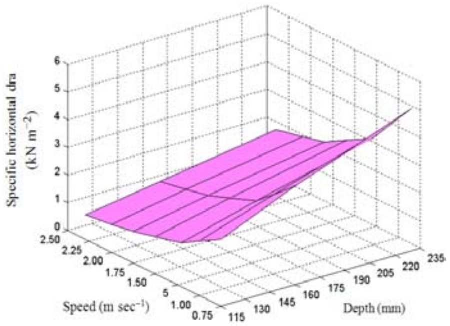


Fig. 8: Effects of plowing depth and forward speed on the vertical specific draft



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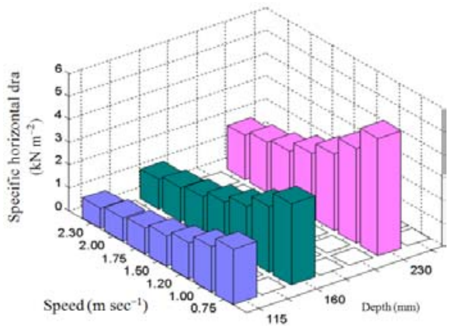
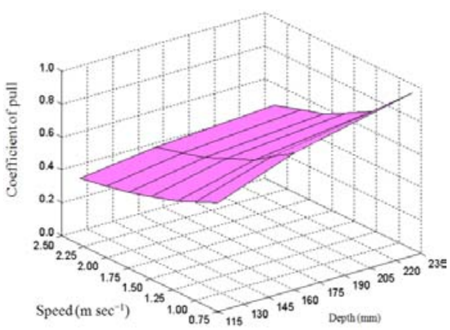


(b)

Fig. 9: Effects of plowing depth and forward speed on the horizontal specific draft



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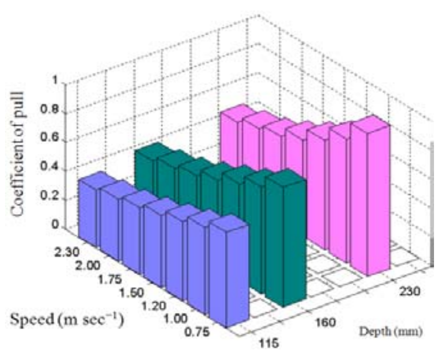

(b)

Fig. 10: Effects of plowing depth and forward speed on the coefficient of pull

Figure 6-10 show the effects of plowing depth and forward speed on the draft, unit draft, vertical specific draft, horizontal specific draft and coefficient of pull.

DISCUSSION

Draft and unit draft: The force required to work (cut and move) the soil varied with both the plowing depth and the forward speed as shown in Table 4 and Fig. 6. Although the increase in draft with either the plowing depth or the forward speed (Fig. 6) appeared to be linear, close inspection of the rates of increase indicated the rate of increase in draft first increased with increases in the forward speed and/or plowing depth and then decreased as shown in Table 8 and 9. For all plowing depths, the observed rate of increase in draft when the forward speed was increased from 0.75-1.20 m sec^{-1} was higher than the observed rate of increase in draft when the forward speed was increased from 1.20-1.75 m sec^{-1} and from 1.75-2.30 m sec^{-1}. However, the rate of increase in the draft observed when the forward speed was increased from 1.20-1.75 m sec^{-1} was lower than the rate of increase in the draft observed when the forward speed was increased from 1.75-2.30 m sec^{-1}. This may indicate that the forward speed of 1.75 m sec^{-1} is the optimum speed. It was, also, observed that the rate of increase in draft when the depth was increased from 115-160 mm was higher than the rate of increase in the draft when the depth was increased from 160-230 mm.

Table 8: The incremental increase in draft with increases in forward speed at various depths

Depth (mm)	Forward speed interval (m sec^{-1})	Increase in draft (kN m^{-1} sec^{-1})
115	0.75-1.20	0.76
	1.20-1.75	0.49
	1.75-2.30	0.51
160	0.75-1.20	1.09
	1.20-1.75	0.64
	1.75-2.30	0.91
230	0.75-1.20	1.51
	1.20-1.75	1.00
	1.75-2.30	2.15

Table 9: The incremental increase in draft with increases in depth at various speeds

Speed (m sec^{-1})	Depth intervals (mm)	Increase in draft (kN m^{-1})
0.75	115-160	77.33
	160-230	70.00
1.20	115-160	80.44
	160-230	72.71
1.75	115-160	82.44
	160-230	75.57
2.30	115-160	87.33
	160-230	85.28

Table 10: Length of roots of common agricultural crops

Crop	Root length (mm)
Egg plant	50-60
Clover	40-50
Corn	30-40
Fava beans	30-40
Wheat (all cereals)	30-40
Cucumber	40
Beans	30
Tomatoes	25
Lutes	20

The unit draft was defined in this study as the draft decided by the width of worked soil (width of plowed strip). The results followed the same trend as those of the draft as shown in Table 4 and Fig. 9. It appears, also, that the plowing depth had more effect on the unit draft than the forward speed. Increasing the depth from 115-230 mm (100%) increased the unit draft by 164.6, 158.3, 157.1 and 159.4% for the forward speeds of 0.75, 1.20, 1.75 and 2.30 m sec^{-1}, respectively. On the other hand, increasing the forward speed from 0.75-2.30 m sec^{-1} (206.6%) increased the unit draft by 46.0, 44.3 and 43.1% for the plowing depths of 115, 160 and 230 mm, respectively. On the average, doubling the plowing depth increased the unit draft by about 159% while doubling the forward speed increased the unit draft by 21.5%.

Mamman and Qui (2005) studied the performance of a chisel plow and found the speed and tillage depth to have more influence on the draft than the plow design. Sahu and Roheman (2006) found that the effect of speed on the draft was less than that of the depth. Al-Suhaibani and Ghaly (2010) reported significantly higher increase in the draft will increase in the plowing depth of a medium size chisel plow compare to those increases caused by the increase in forward speed.

Shallow seed placement (less than 25 mm) is recommended for most crops that are directly seeded (Collins and Fowler, 1996). However, the depth of the crop roots to be raised is a deterministic factor of plowing depth, while the availability of time and implement width will determine the speed required to finish the study on time (Boydaf and Turgut, 2007). The results obtained from this study indicated that the depth has more effect on the draft. Therefore, the depth of plowing should be determined based on the root length as shown in Table 10. Al-Suhaibani and Ghaly (2010) made similar recommendations based in their study with a medium size chisel plow.

Specific draft: The vertical specific draft is defined in this study as the draft per worked vertical cross sectional area. The results presented in Table 5 and Fig. 10 shows that increasing the plowing depth and/or the forward speed increased the vertical specific draft. Increasing the plowing depth from 115-230 mm (100%) increased the vertical specific draft by 32.7, 27.7, 28.7 and 29.8% for the speeds of 0.75, 1.20, 1.75 and 2.30 m sec^{-1}, respectively. On the other hand, increasing the forward speed from 0.75-2.30 m sec^{-1} (206.6%) increased the vertical specific draft by 46.2, 43.4 and 43.1% for the plowing depths of 115, 160 and 230 mm, respectively. On the average, doubling the plowing depth increased the vertical specific draft by 29.5% while doubling the forward speed increased the specific draft by 21.4%.

The horizontal specific draft is defined in this study as the draft per worked horizontal area per second. The results showed that increasing the plowing depth and/or reducing the forward speed increased the horizontal specific draft. Increasing the plowing depth from 115-230 mm (100%) increased the horizontal specific draft by 165.8, 155.7, 157.1 and 166.0% for the forward speed of 0.75, 1.20, 1.75 and 2.30 m sec^{-1}, respectively. On the other hand, increasing the forward speed from 0.75-2.30 m sec^{-1} (206.6%) reduced the horizontal specific draft by 52.3, 53.1 and 53.3% for the plowing depths of 115, 160 and 230 mm, respectively. On the average, doubling the plowing depth increased the horizontal specific draft by 161.15%, while doubling the forward speed reduced the horizontal specific draft by 25.6%.

It must be noted that the vertical specific draft has much higher values than those of the horizontal specific draft. Indicating that the depth of plowing has significantly more effect on the draft than the forward speed. Increasing the depth increased both the vertical draft and horizontal draft while increasing the forward speed increased the vertical draft and reduced the horizontal draft. This could have a significant impact on the economical tillage.

Van Muysen *et al*. (2000) stated that the specific draft is affected by the tool geometry. Owen (1989) found the vertical force to decrease linearly with the plowing depth while the horizontal force to increase quadratically with the plowing depth. Al-Suhaibani and Ghaly (2010) reported higher values for the vertical draft than those of horizontal draft.

Coefficient of pull: The coefficient of pull is defined in this study as the draft divided by the total weight of the plow and the worked soil. The weight of the worked soil was determined by multiplying the soil density by the volume of the worked soil. The volume of the worked soil was determined by multiplying the plowed depth by the width of plowed strip by the forward speed. The results showed that increasing the depth of plowing increased the coefficient of pull for all forward speeds. Increasing the plow depth from 115-230 mm (100%) increased the coefficient of pull by 92.1, 68.0, 61.3 and 58.5% for the forward speeds of 0.75, 1.20, 1.75 and 2.30 m sec^{-1}, respectively. On the other hand, increasing the forward speed from 0.75-2.30 m sec^{-1} (206.6%) reduced the coefficient of pull by 19.6, 26.9 and 33.7% for the plowing depths of 115, 160 and 230 mm, respectively.

CONCLUSION

The effects of plowing depth and forward speeds on draft, unit draft, vertical draft, horizontal draft and coefficient of pull were evaluated. The results indicated that increasing the plowing depth and/or the forward speed increased the draft, unit draft and vertical specific draft. Also, increasing the plowing depth increased the horizontal specific draft and the coefficient of pull, while increasing the speed decreased the horizontal specific draft and the coefficient of pull.

About 21.8% of the draft force was directed towards cutting the soil and 78.2% was consumed in pulverization of soil particles. The values of the vertical specific draft were much higher than those of the horizontal specific draft for all plowing depths and forward speeds. The plowing depth had more pronounced effect on the draft, unit draft, specific draft and coefficient of pull than the forward speed. The optimum forward speed was 1.75 m sec^{-1}. The recommended plowing depth should be based on the type of crop (depth of the root system).

Shallow seed placement (less than 25 mm) is recommended for most crops that are directly seeded. However, the depth of the crop roots to be raised is a deterministic factor of plowing depth, while the availability of time and implement width will determine the speed required to finish the study on time. The results obtained from this study indicated that the depth has more effect on the draft. Therefore, the depth of plowing should be determined based on the root length. These results again emphasize the importance of selecting the proper forward speed and tillage depth in order to reduce the cost of the tillage operation while maintaining optimum seed bed conditions.

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