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Comparative Study of the Kinetic Parameters of Three ChiselPlows Operating At DifferentDepthsand Forward Speed In A Sandy Soil

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---ABSTRACT---
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. Field experiments were conducted using a fully instrumented MS 3090 tractor to measure the draft of a heavy duty 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. The effects of plowing depth and forward speed 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. About 16.6% of the draft force was directed towards cutting the soil and 83.4% 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/s. The recommended plowing depth should be based on the type of crop (depth of the root system).

KEYWORDS:Tillage, draft, unit draft, specific draft, coefficient of pull, sandy soil, instrumentation, chisel plow.

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I. INTRODUCTION

Tillage is defined as a process aimed at creating a desired final soil condition for seeds from some undesirable initial soil conditions through manipulation of soil with the purpose of increasing crop yield (Gil and Vanden Berg, 1968). This can be achieved using several tillage implements. However, the selection of tillage implements for seedbed preparation and weed control depends on soil type and condition, type of crop, previous soil treatments, amount of crop residues and weed type. One of the primary tillage implements widely used by farmers for the initial soil working operations is the chisel plow which functions most effectively when the soil is dry and firm (Srivastava et al., 1993).

The tillage operation requires the most energy and power spent on farms (Finner and Straub, 1985). 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 givin 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 Donis, 2009).The effects of soil conditions, tillage depth and forward speed on soil translocation by chisel plows,the specific draft (force per cross sectional area of worked soil) and energy use were investigated by Arvidsson (2004) and Van Muysen et al. (2000). They found that the specific draft was affected by the depth of tillage, forward speed and differences in implement geometry.

Models were developed to predict draft for tillage tools based on soil conditions, soil properties and implement width (Sahu and Raheman, 2006). 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 time 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.Mamman and Qui (2005) studied the draft performance of a chisel plow model using a soil bin.The design parameters considered were: nose angle, slide angle, depth and speed. The draft increased with increases in tillage depth and the levels of nose and slide angles and the cutting edge height. Brown et al. (1989) stated that manufacturers of tillage implements tend to overdesign their products due to a lack of proper design and analysis of tools and the technical expertise required to optimize the strength of an implement. 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 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. Brown et al. (1989) evaluated the stress on the chisel plow using a finite element analysis and reduced the weight by 23% without causing excessive stress on the plow.

The main aim of this study was to evaluate the performances of three chisel plowsof different widths, weights and number and distribution of shanks. The specific objectives were to study the effects of plow weight, plowing depth and width and forward speed on: (a) draft, (b) unit draft, (c) specific draft and (d)coefficient of pull.

II. MATERIALS AND METHODS

2.1.Tractor and Instrumentation System

A fully instrumented Massy Ferguson (MF) 3090 tractor (Figure 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 the drawbar pull (b) two wheel torque transducers, to measure the 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 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 (Al-Suhaibani et al., 2010).

The draft was measured using a drawbar dynamometer (Figure 2a) 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 as shown in Figure 2b. 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 (Figure 2c) 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).

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. The data was displayed on a lap top computer as shown in Figure 3.

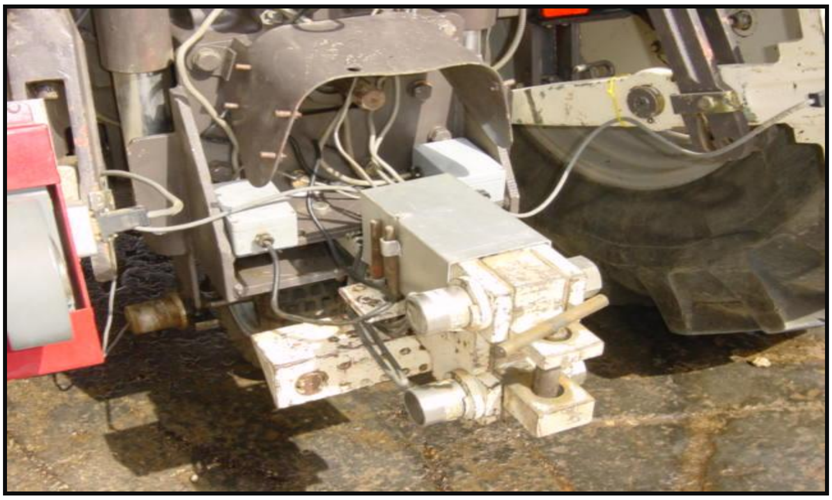
2.2.Chisel Plows

Three chisel plows of different weights, widths and number of shanks were used in this study: (a) a medium size Massy Ferguson (Denmark) chisel plow (Model MF 38, serial No. L4078) which weighed 380 Kg (3.785 kN) and had a width of 180 cm and 7 shanks distributed in 3 rows, (b) a heavy duty Mazia (Italy) chisel plow (Model CMP115-R, Serial No. 59062) which weighed 415 Kg (4.133 kN) and had a width of 315 cm and 15 shanks distributed in 2 rows and (c) a super heavy duty Galucho (Portugal) chisel plow (Model STT-15, Serial No. G 99-343-499) which weighed 680 Kg (6.773 kN) and had a width of 385 cm and 15 shanks distributed in 2 rows. The specifications of the plows are shown in Table 2. The three chisel plows are shown in Figure 4. The distributions of the shanks on the plow frames are shown in Figure 5.

Figure 1. The fully instrumented tractor.

Table 1. Tractor specifications.

Parameter	Value
Power	100 HP (75 kW)
Weight	4827Kg (48.077 kN)
Weight on front wheels	1886 Kg (18.785 kN)
Weight on rear wheels	2941 Kg (29.292 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



(a) The draw bar dynamometer.

(b) The fifth wheel.

(c) The depth measuring device

Figure 2. The devices used for measuring draft, forward speed and tillage depth.

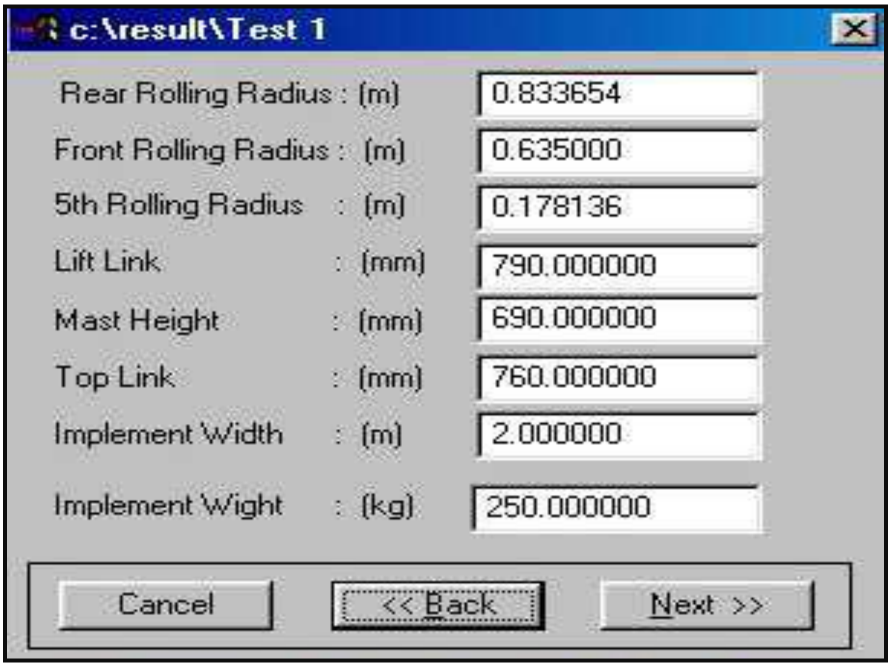


Figure 3.Alap top screen showing data.

Table 2. Specifications of chisel plows.

Parameter	Medium	Heavy duty	Super heavy duty
Model	1-1	CMP/15-R.	STT-15
Serial No	603	59062	G99-343499
Manufacture company	IH	MARZIA	GALUCHO
Country	Denmark	Italy	Portugal
Total weight (kg)	380	415	680
(kN)	(3.785)	(4.133)	(6.773)
Width of plow (cm)	190	335	385
Total width of tillage (cm)	210	337.5	412.5
Number of shanks	7	15	15
Width of chisel tool (cm)	5	6	6
Width of shank (cm)	5	5	5
Thickness of shank (cm)	2.5	2.5	2.5
Shank stem angle (º)	50	51	42
Number of rows	3	2	2
Number of shanks in first row	2	8	7
Distance between shanks in first row (cm)	120	45	55
Number of shanks in second row	2	7	8
Distance between shanks in second row (cm)	60	45	55
Number of shanks in third row	3		
Distance between shanks in third row (cm)	90		
Total width of cut by tools (cm)	35	90	90
Percent of cut soil (%)	16.6	26.7	21.8
Width of pulverization soil (cm)	175	247.5	322.5
Percent of pulverized soil (%)	83.4	73.3	78.2

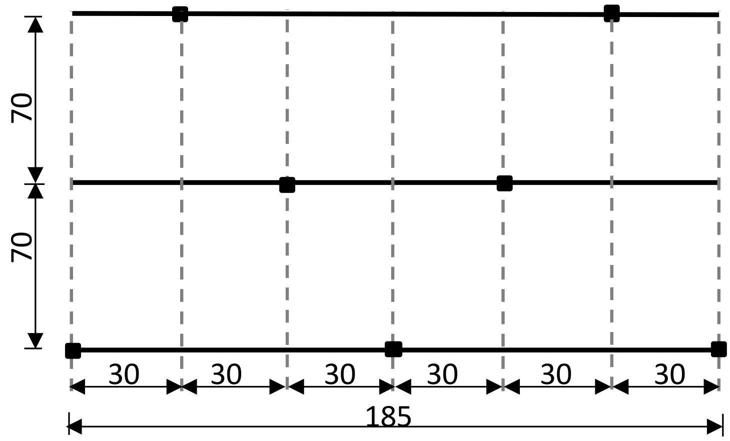
Tonne= 9.96 kN

(a) Medium plow

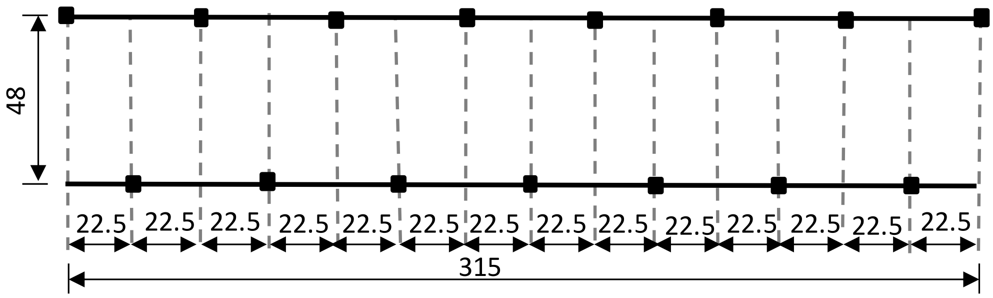
(b) Heavy dutyplow

(c) Super heavy dutyplow

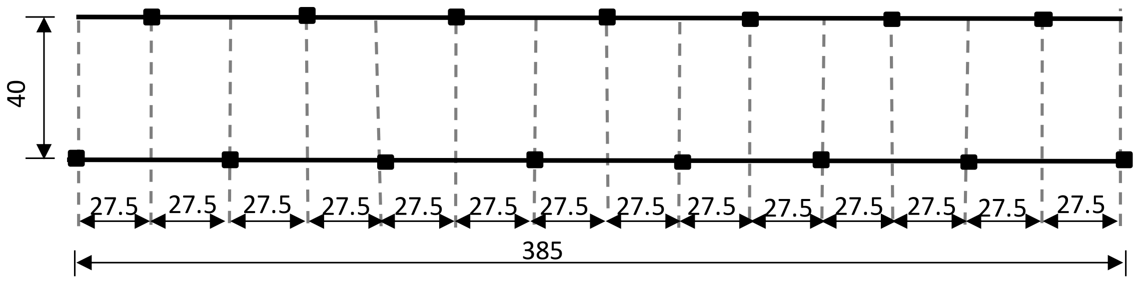
Figure 4. Chisel plows used in the study.



(a) Medium plow



(b) Heavy duty plow



(c) Super heavy duty plow

Figure 5. Distribution of shanks on the plow frame (Dimensions are in cm).

2.3.Field Experiments

Experiments were conducted using the fully instrumented MF 3090 tractor to measure the draft requirement of three chisel plows in a sandy loam soil (Table 3) over wide ranges of forward speeds (0.75, 1.25, 1.75 and 2.25 m/s) and tillage depths (115, 160 and 230 cm) at the Agricultural Research and Experimental Farm of the King Saud University in Dirab. This resulted in 12 treatment combinations foe each plow with a total of 36 treatment combinations. Ten measurements were taken for each treatment combinations at 5 minutes intervals. The data logger monitored and recorded the data for depth, speed and draft during the field experiments. The laptop displayed the values of the measured parameters and analyzed the data.

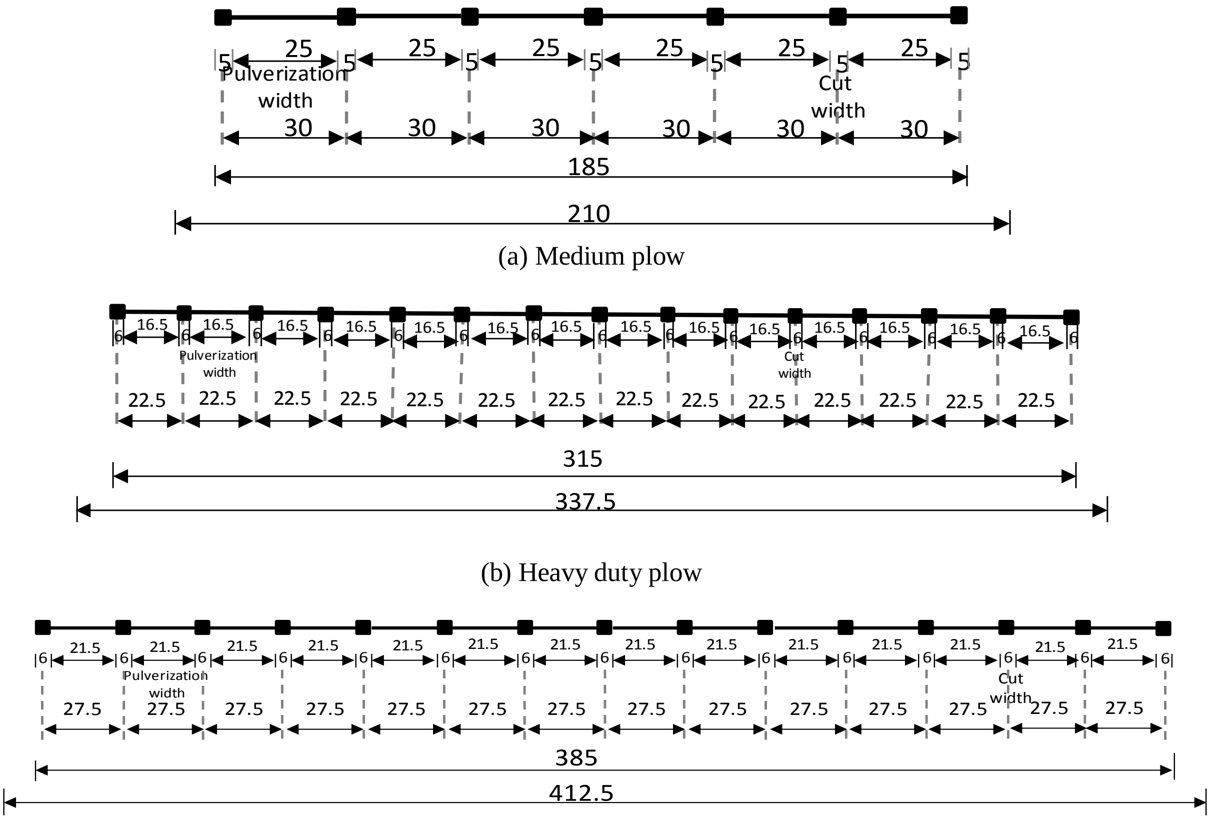
III. RESULTS AND DISCUSSION

3.1.Plowed Strip

The widths of plows were 180,315 and 375 cm while the widths of worked soil (plowed strip) were 210, 337.5 and 412.5 cm for the medium, heavy and super heavy duty plows, respectively. The distances between the paths of the shanks and the widths of the worked soils (plowed strips) are shown in Figure 6. The total width of

Table 3. Soil characteristics

Parameter	Value
Moisture content (%)	
At 7 cm	8.3
At 21 cm	13.4
Bulk density	1.4 kg/m^3
Texture	Medium
Drainage	Moderately drained
Permeability	Slow (0.36 x 10^{-2} m/h)
pH	5.8
Particle size distribution (%)	
Clay	21
Silt	20
Sand	59
Classification	Sandy loam



(a) Medium plow

(b) Heavy duty plow

(c) Super heavy duty plow

Figure 6. Distance between the paths of shanks (Dimensions are in cm).

cut was calculated by multiplying the number of shanks by the width of cutting tool. The remaining part of the width of the plowed strip was considered to be the width of pulverized soil. Accordingly, the plow shanks (cutting tools) were able to cut 16.6, 26.6 sand 21.8% of the total strip while the pulverized areas were 84.4, 73.3 and 78.3% for the medium, heavy and super heavy duty plows, respectively.

3.2.Draft

Table 4 shows the results of the measured draft. The effects of plowing depth and forward speed on the draft are shown in Figure 7. The force required to work (cut and move) the soil varied with both the plowing depth and forward speed and was affected by the width of the plow and the number of shanks. When the speed was increased from 0.75 m/s to 2.25 m/s (200%), the draft was increased by 38.34-45.18%, 43.10-46.18% and 17.81-15.72% (depending on the plowing depth) for the medium, heavy and super heavyduty plows,

Table 4. Drafts (kN), Unit draft (kN/m) and Draft per shank (kN)

Chisel Plow	Speed (m/sec)	Depth(mm) 115			160			230		
		Draft	Unit draft	Draft /shank	Draft	Unit Draft	Draft /shank	Draft	Unit Draft	Draft /shank
Medium	0.75	3.01	1.43	0.43	5.38	2.56	0.77	8.19	3.90	1.18
	1.25	3.61	1.72	0.52	6.44	3.07	0.92	9.47	4.51	1.35
	1.75	3.74	1.78	0.53	7.11	3.39	1.00	10.51	5.00	1.50
	2.25	4.37	2.08	0.62	7.85	3.73	1.11	11.33	5.40	1.63
Heavy	0.75	3.14	0.92	0.21	5.54	1.10	0.37	8.33	2.47	0.56
	1.25	3.76	1.11	0.25	6.56	1.94	0.44	9.60	2.84	0.64
	1.75	4.11	1.21	0.27	7.41	2.20	0.49	10.58	3.13	0.70
	2.25	4.59	1.36	0.31	8.01	2.37	0.53	11.92	3.53	0.79
Super heavy	0.75	7.52	1.82	0.50	11.00	2.67	0.73	15.90	3.85	1.06
	1.25	7.86	1.91	0.52	11.49	2.79	0.77	16.58	4.02	1.11
	1.75	8.13	1.97	0.54	11.84	2.87	0.79	17.13	4.15	1.14
	2.25	8.41	2.04	0.56	12.34	2.99	0.82	18.31	4.44	1.22

No. of shanks per medium plow =7
No. of shanks per heavy duty plow =15
No. of shanks per super heavy duty plow =15

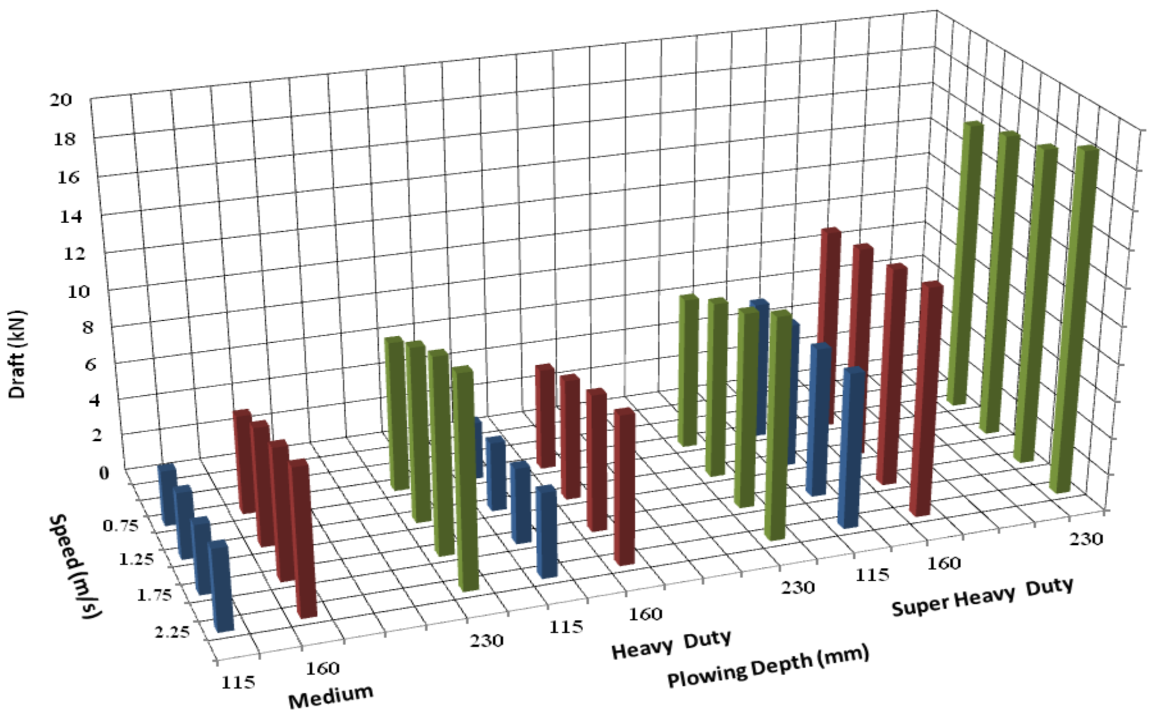


Figure 7. Effects of forward speed and depth of tillage on the draft of various chisel plows (M= Medium; H= Heavy duty; S= Super heavy duty)

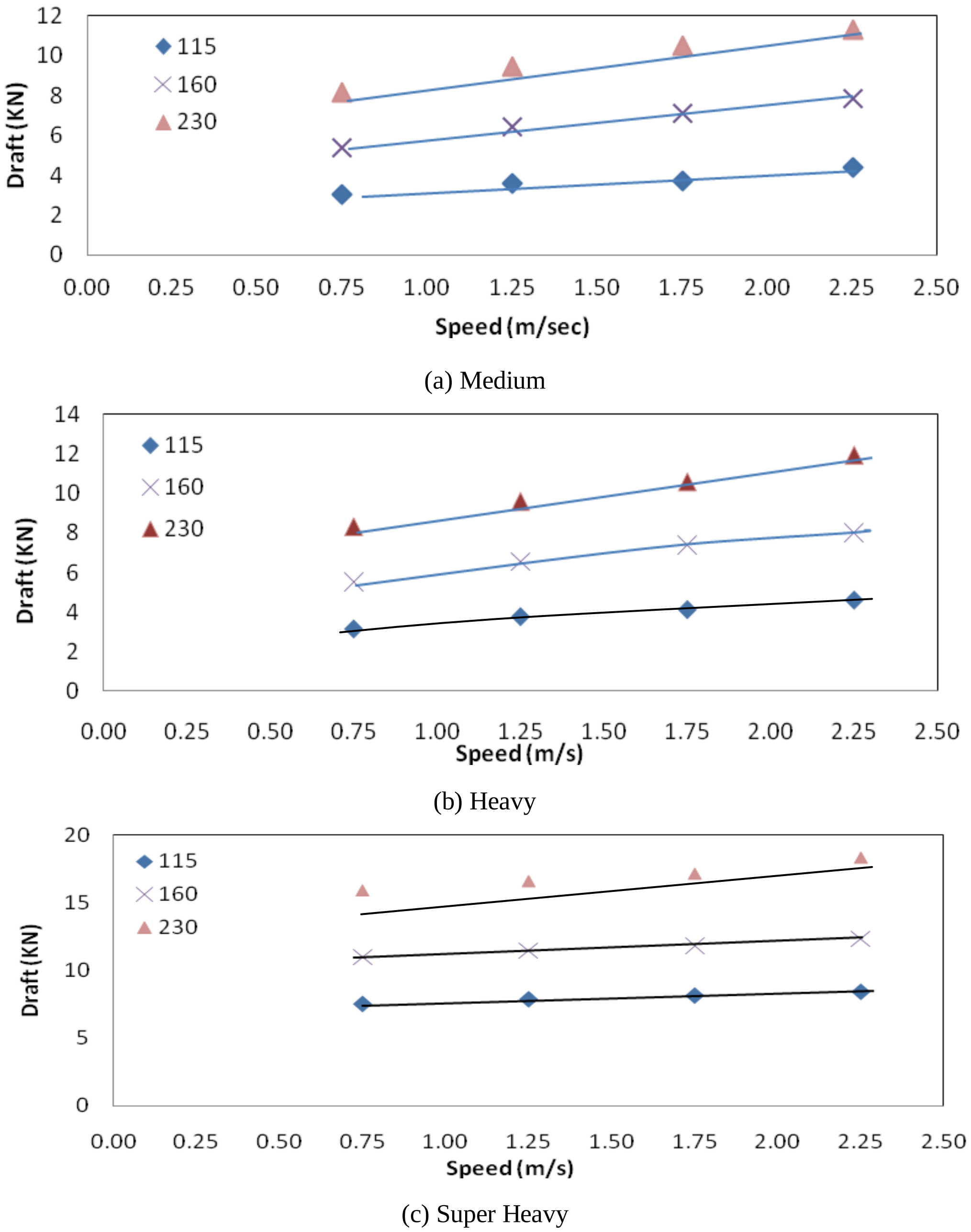
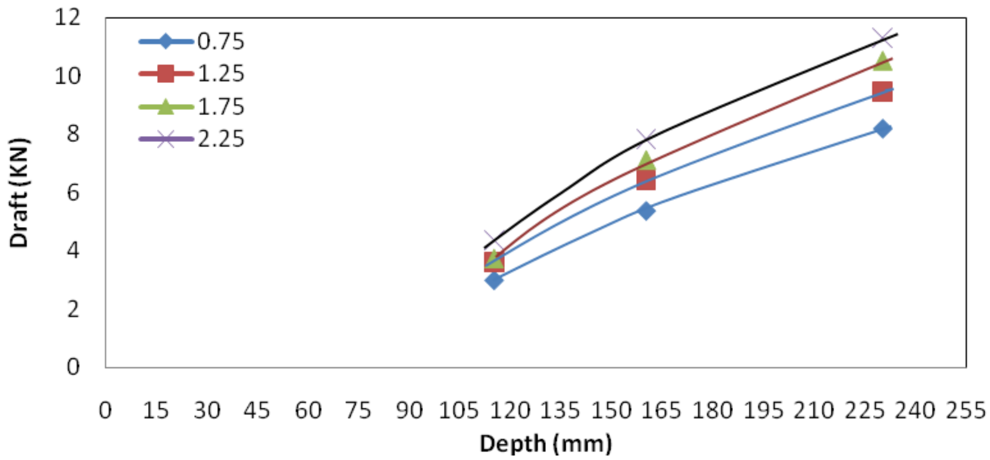


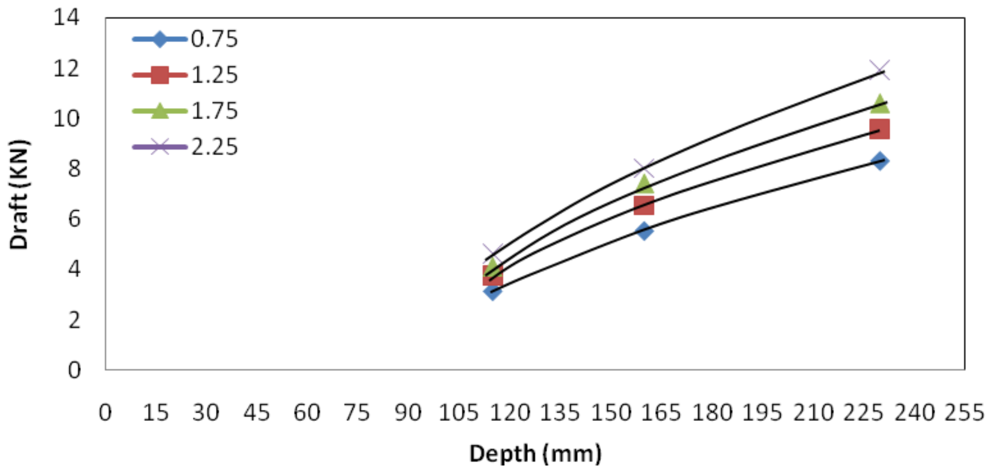
Figure 8. Effects of forward speed on draft

with the heavy duty plow followed by the medium plow and super heavy duty plow. For all plows and all depths, the increases in the draft with the increases in the forward speed appears to be linear (Figure 8)

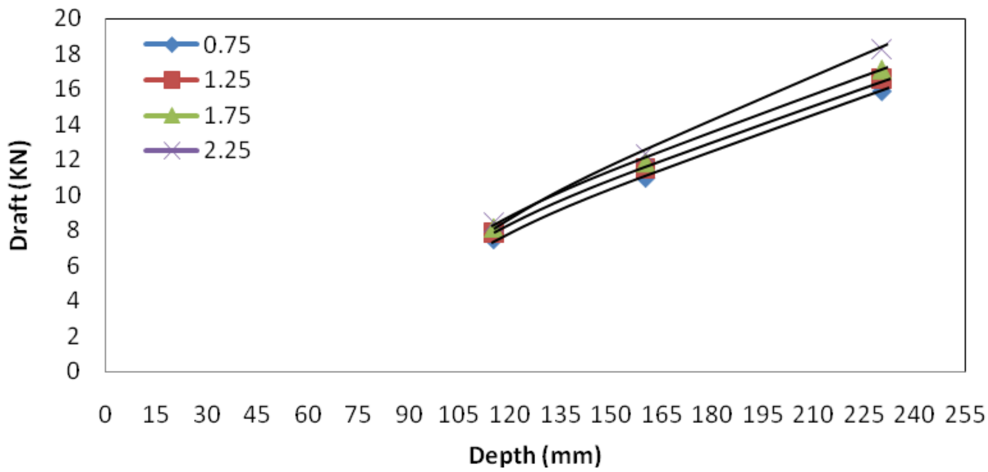
When the tillage depth was increased from 115 mm to 230 mm (100%), the draft was increased by 159.27-169.10%, 159.69-165.29% and 111.44-117.72% (depending on the forward speed) for the medium, heavy and super heavy duty plows, respectively. The percent increase in the draft that resulted from increased plowing depth was the lowest for the heavy duty plow and the medium and heavy plows appeared to have similar increases. For all plows and forward speeds, the increases in the draft with increases in plowing depth did not appear to be linear (Figure 9). The results also showed that the rates of increase in the draft (47-80%) when the plowing depth was increased from 115 mm to 160 mm (39%) was higher than the rates of increase (44-50%) in the draft when the plowing depth was increased from 160 mm to 230 mm (61%) for all plows at all forward speeds.



(a) Medium



(b) Heavy



(c) Super Heavy

Figure9. Effect of plowing depth on draft

The results obtained from the present study showed that the plowing depth had more pronounced effect on the draft than the forward speed. Increasing the plowing depth increased the volume of the soil to be cut, moved and pulverized which required more force. Similar results were reported in the literature (Naderloo et al., 2009; Al-Janobi and Al-Suhaibani, 1998 and Onwualua and Watts, 1998). Abbaspour-Gilandeh et al. (2006) reported increased draft with increased forward speed and tillage depth and stated that the tillage depth had

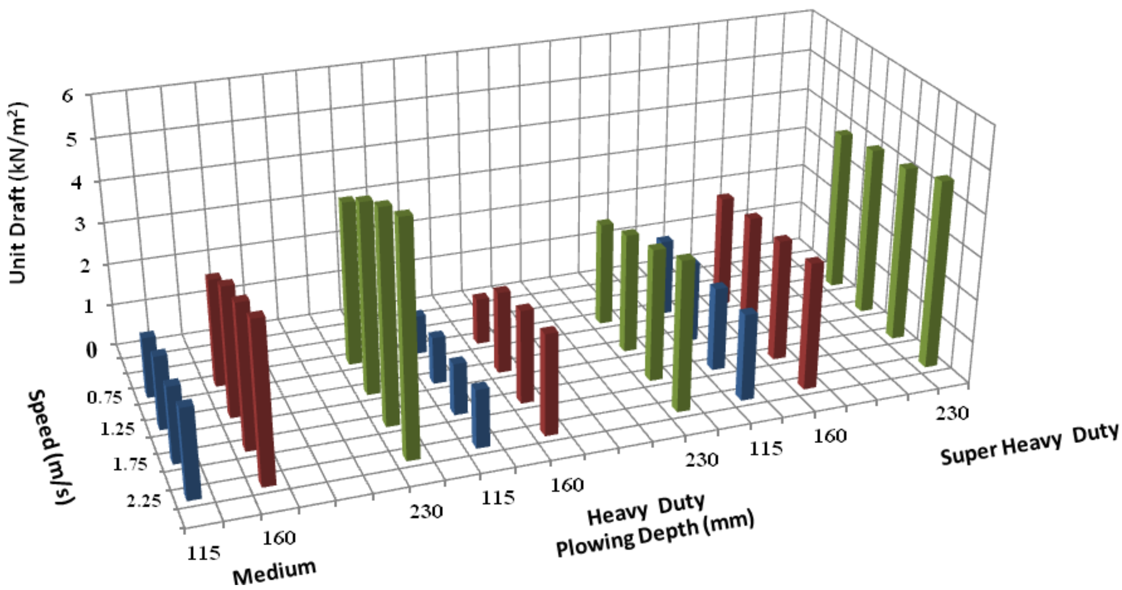


Figure 10. Effects of forward speed and depth of tillage on the unit draft of various chisel plows (M= Medium; H= Heavy duty; S= Super heavy duty)

greater effect on the draft than the forward speed. Chen et al. (2005) stated that draft of implement changes with its operational speed. Sahu and Roheman (2006) reported that the effect of speed on the draft was less than that of the depth. Chen (2002) reported that the speed effects on draft force were less pronounced than those of the depth. Al-Suhaibani and Ghaly (2010) and Al-Suhaibani et al. (2010) reported significantly higher increases in the draft with increased depth than those observed with increased forward speed. 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. Kushwaha and Linke (1996) reported a linear relationship between forward speed and draft for tillage implements under the critical speed range of 3-5 m/s. Tsimbaet al. (1999) reported a relationship between the depth of plowing and soil characteristics.

3.3.Unit Draft

The unit draft is defined in this study as the draft per unit width of the worked soil (width of plowed strip). Table 4 shows the results of the calculated unit draft. The effects of plowing depth and forward speed on the unit draft for the various plows are shown in Figure 10. The results of the unit draft followed same trend as those of the draft. However, it appears that the plowing depth and width had greater effect on the unit draft than the forward speed. Increasing the depth from 115 mm to 230 mm (100%) increased the unit draft by 160-173, 160-168 and 112-117% while increasing the forward speed from 0.75 m/s to 2.25 m/s (200%) increased the unit draft by 38-45, 43-47 and 12-15% for the medium, heavy duty and super heavy duty plow, respectively. On the average, tripling the forward speed increased unit draft by 12-47%(depending on the type of plow and plowing depth) while doubling the plowing depth increased the unit draft by 112-173% (depending on the type of plow and the forward speed). The results showed that for all speeds and plowing depths tested, the super heavy duty plow had the highest unit draft followed by the heavy duty plow and medium plow.

The increase in unit draft will significantly affect the fuel consumption and the cost of production. Abbaspour-Gilandeh et al. (2006) and Alimardani et al. (2007) showed a correlation between the draft and fuel consumption.Grisso et al. (2011) reported a linear relationship between draw bar pull and fuel consumption. Serrano et al. (2005) reported a linear relationship between unit draft and fuel consumption.

Shallow seed placement (less than 25 mm) is recommended for most crops that are directly seeded (Collins ad Fowler, 1996). However, the depth of the crop roots (Table 5) will be an important factor in determining plowing depth, while the availability of time and the plow width will determine the forward speed required to finish the work on time (Boydof and Turgut, 2007; Al-Suhaibani and Ghaly, 2010). The results obtained in this study indicated that the plowing depth has more effect on the draft than the forward speed. Therefore, the depth of plowing should be determined based on the root length since increasing the forward speed will improve the quality of seedbed and will not proportionally increase the draft. Al-Suhaibani and Ghaly (2010) and Al-Suhaibani et al. (2010) made similar recommendations.

Table 5. Length of roots of common 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

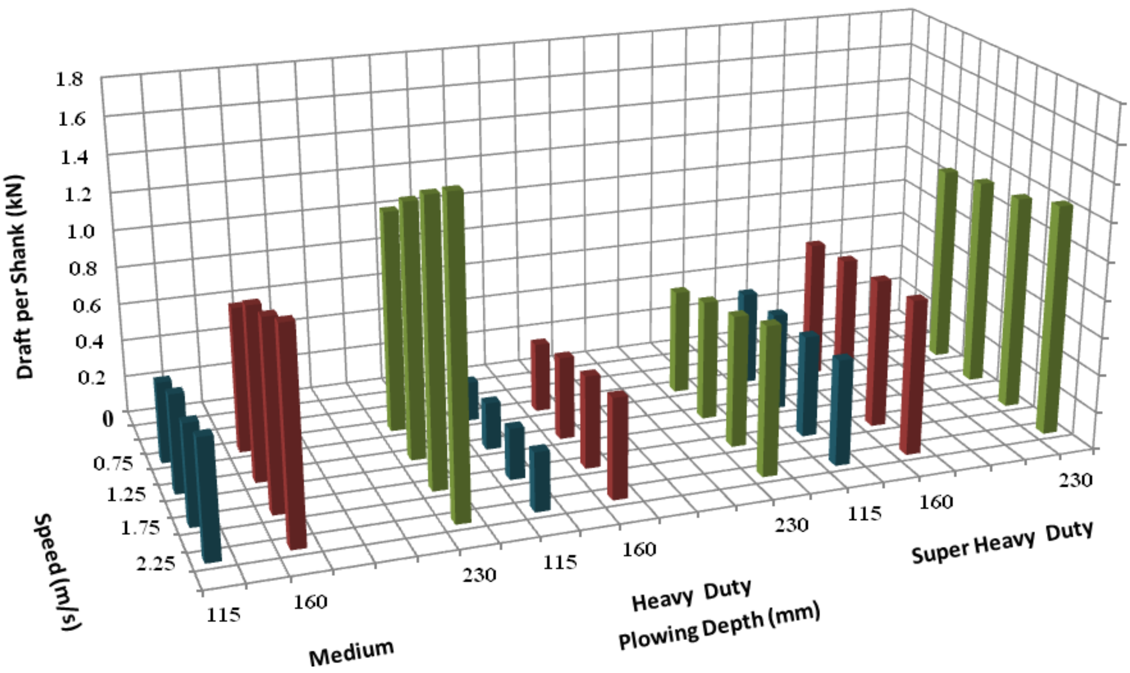


Figure 11. Effects of forward speed and depth of tillage on the draft per shank of the various chisel plow (M= Medium; H= Heavy duty; S= Super heavy duty)

3.4.Draft Per Shank

The draft per shank was calculated by dividing the total draft by the number of shanks (Table 4). Figure 11 shows the effects of plowing depth and forward speed on draft per shank for the three plows. The results showed that increasing the plowing depth and forward speed increased the draft per shank for all plows. However, the super heavy duty plow appears to have higher energy requirement followed by the heavy duty plow and medium plow. Collins and Flower (1996) studied the effects of seeding depth and operating speed on the draft force during direct seeding and reported significant increase in the draft force per opener when the seeding depth was increased from 1 cm to 5 cm while increasing the operating speed produced a small but linear increase in draft force per opener. Raper (1999) studied the effect of operational depth on the draft per shank (curved) and reported a significant increase (390%) in the draft per shank when the operation depth was increased from 23 cm to 38 cm. Raper (2007) investigated the effect of operational depth on the draft per shank (Terramax^{TM}) and reported a significant increase (225%) in the draft per shank when the operational depth was increased from 20 cm to 40 cm. Wolf et al. (1981) reported that the draft per subsoiler shank increased from 2.52 kN to 6.20 kN as subsoiling depth was increased from 28 cm to 44 cm.

3.5.Specific Draft

The vertical and horizontal specific drafts were calculated from the draft (Table 6). The vertical specific draft was defined as the draft per projected vertical unit area of tilled soil (cross sectional area of the worked soil). The cross sectional area of the worked soil was calculated by multiplying the depth of plowing by the

Table 6. Vertical and horizontal specific draft (kN/m^2)

Chisel Plow	Speed (m/sec)	Depth(mm) 115		160		230	
		Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
Medium	0.75	1.25	1.91	1.60	3.41	1.79	5.20
	1.25	1.49	1.43	1.92	2.56	1.96	3.43
	1.75	1.55	1.02	2.12	1.93	2.18	2.86
	2.25	1.81	0.90	2.34	1.62	2.35	2.35
Heavy duty	0.75	0.81	1.24	1.03	2.19	1.07	3.29
	1.25	0.97	0.93	1.21	1.62	1.24	2.37
	1.75	1.06	0.70	1.37	1.25	1.36	1.79
	2.25	1.28	0.59	1.48	1.03	1.54	1.54
Super heavy duty	0.75	1.58	2.34	1.67	3.56	1.68	5.20
	1.25	1.66	1.59	1.74	3.32	1.75	3.35
	1.75	1.71	1.13	1.79	1.64	1.81	2.37
	2.25	1.77	0.87	1.87	1.30	1.93	1.93

width of the plowed strip. The horizontal specific draft was defined as the draft per the horizontal plowed unit area per second. The horizontal plowed unit area per second was calculated by multiplying the forward speed by the width of the plowed strip. The effects of plowing the depth and forward speed on the vertical and horizontal specific drafts are shown in Figure 12.

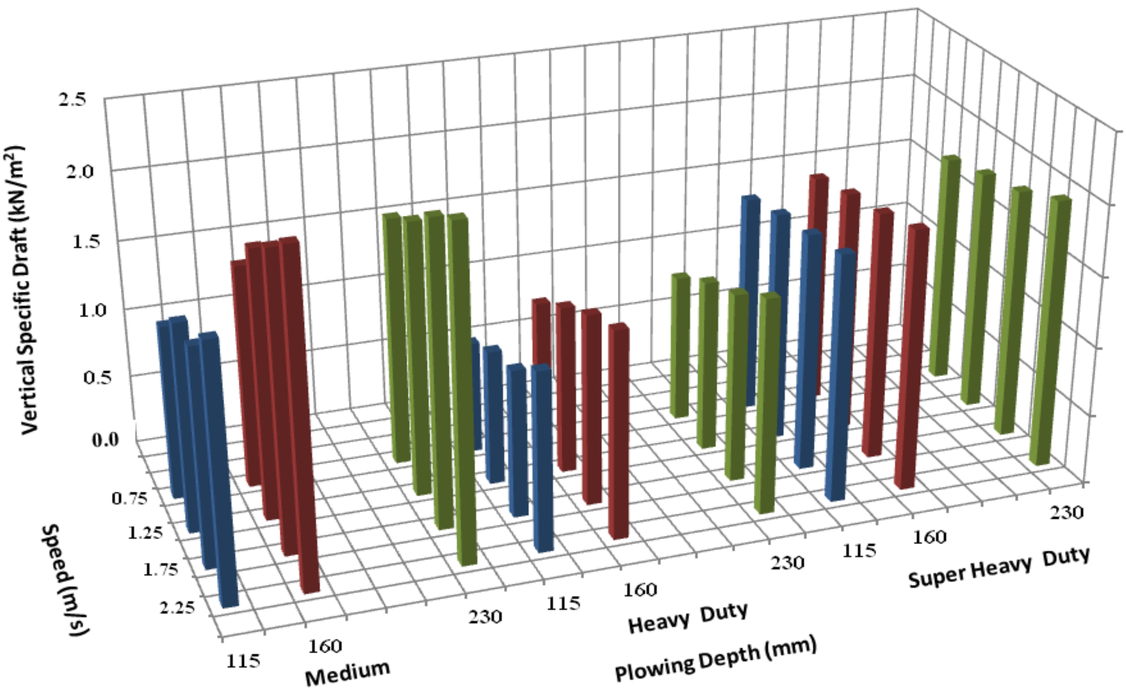
Increasing the plowing depth and/or the forward speed increased the vertical specific draft. Increasing the plowing depth from 115 mm to 230 mm (100 %) increasedthe vertical specific draft by 29-43, 20-22 and 6-9 % while increasing the forward speed from 0.75 m/s to 2.25 m/s (200 %) increased the vertical specific draft by 31-44, 43-88 and 12-15% for the medium, heavy duty and super heavy duty plows, respectively.On the other hand, increasing the plowing depth and/or decreasing the forward speed increased the horizontal specific draft. Increasing the plowing depth from 115 mm to 230 mm (100%) increased the horizontal specific draft by 161-172, 161-165 and 122-127 % while increasing the forward speed from 0.75 m/s to 2.25 m/s (200%) decreased the horizontal specific draft by 54-58, 52-53 and 63% for the medium, heavy duty and super heavy duty plows, respectively.

The results indicated that the plowing depth has more effect on the horizontal force than the vertical force. Owen (1989) found the vertical force to increase linearly with the plowing depth while the horizontal force to increase quadratically with the plowing depth. Arvidsson and Hillerstrom (2010) reported 20% increase in specific draft with increased tine width from 50-120 mm. Arvidsson et al. (2004) reported increases in specific draft (19.5%) with increased working depth (from 17 cm to 21 cm) for a chisel plow. Al Janobi and Al-Suhaibani (1998) observed increasesin the specific draft with an increase in tillage depth and speed for several implements (offset disk harrow, moldboard plow, disk plow and chisel plow) tested on sandy loam soil.

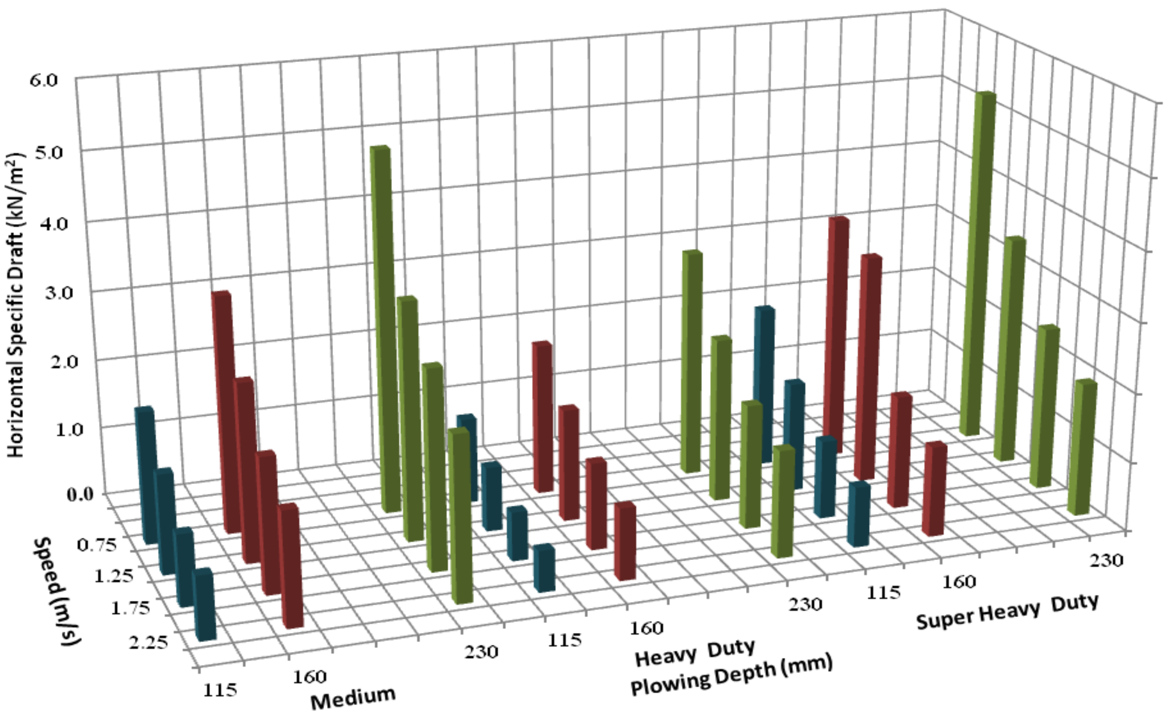
3.6.Coefficient of Pull

The coefficient of pull was defined as the total draft divided by the weight of the plow plus the weight of the tilled soil. The weight of the tilled soil was calculated from the volume of tilled soil (Table 7) and soil density. The volume of the tilled soil was calculated by multiplying the plowing depth by the width of plowedstrip by the forward speed. Figure 13 show the calculated values of the coefficient of pull for the three plows at various plowing depths and forward speeds.

The measured total draft was the power required to pull the plow weight and to work the soil. The results showed that the coefficient of pull was affected by the plowing depth and the forward speed both of which have significant effect on the volume of worked soil. Increasing the forward speed from 0.75 m/s to 2.3 m/s (200%) decreased the coefficient of pull by 37-54, 41-44 and 51-56% while increasing the plowing depth



(a) Vertical specific draft



(b) Horizontal specific draft

Figure 12. Effects of forward speed and depth of tillage on vertical and horizontal specific draft of various chisel plows (M= Medium; H= Heavy duty; S= Super heavy duty)

from 115 mm to 230 mm (100%) increased the coefficient of pull by 42-96, 46-53 and 16-18% for the medium, heavy duty and super heavy duty plows, respectively. The results showed that increasing the plowing depth significantly.

Table 7. Soil moved by the plows (m^3) and coefficient of pull (kN/kN)

Chisel Plow	Speed (m/sec)	Depth (mm)					
		115		160		230	
		Soil volume (m^3)	Coefficient of pull (kN/kN)	Soil volume (m^3)	Coefficient of pull (kN/kN)	Soil volume (m^3)	Coefficient of pull (kN/kN)
Medium	0.75	1.81	0.30	2.52	0.43	3.62	0.59
	1.25	2.90	0.26	4.03	0.36	5.80	0.40
	1.75	4.23	0.20	5.88	0.29	8.45	0.32
	2.50	5.55	0.19	7.72	0.26	11.10	0.27
Heavy duty	0.75	2.91	0.22	4.05	0.30	5.82	0.34
	1.25	4.66	0.18	6.48	0.25	9.32	0.29
	1.75	6.79	0.15	9.45	0.20	13.58	0.21
	2.50	8.93	0.13	12.42	0.17	17.85	0.19
Super heavy duty	0.75	3.56	0.39	4.90	0.45	7.12	0.50
	1.25	5.69	0.30	7.92	0.33	11.39	0.36
	1.75	8.30	0.23	11.55	0.25	16.60	0.26
	2.50	10.9	0.19	15.18	0.20	21.82	0.22

Width of cut for medium plow = 210 cm
Weight of medium plow = 3.785 kN
Width of cut for heavy duty plow = 337.5 cm
Weight of heavy duty plow = 4.133 kN
Width of cut for super heavy duty plow = 412.5 cm
Weight of super heavy duty plow = 6.773 kN
Tonne = 9.96 kN
Soil density = 350 kg/m^3 (3.486 kN/m^3)
Soil volume = plowed depth x width of plowed strip x forward speed

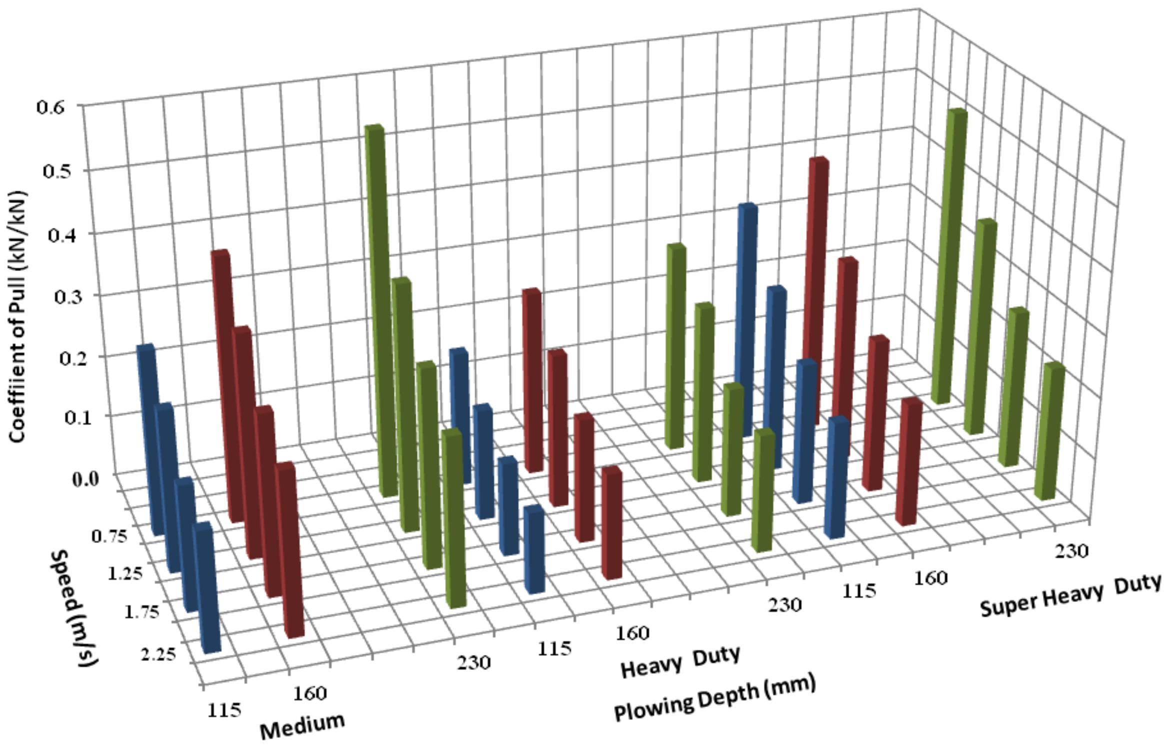


Figure 13. Effects of forward speed and depth of tillage on coefficient of pull of various chisel plows (M= Medium; H= Heavy duty; S= Super heavy duty)

increase the power required to pull the plow while increasing the speed does not proportionally increase the power required but may improve the tillage quality.

IV. CONCLUSION

The effects of plowing depth and forward speeds on draft, unit draft, draft per shank, 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 speed decreased the horizontal specific draft and the coefficient of pull. About 16.6% of the draft force was directed towards cutting the soil and 83.4% 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. 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 work 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.

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