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Influence of Chisel Plow Shank Shape on Horizontal and Vertical Force Requirements

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تأثير شكل قصبة المحراث الحفار على متطلبات القوة الأفقية والرأسية

عبد الرحمن الجنوبي ومحمد وهبي وعبد الواحد أبو كريمة وسعد الحامد

خلاصة: تم قياس القوى الأفقية والرأسية المؤثرة على ثلاث محاريث حفارة ذات قصبات بأشكال مختلفة وذلك في تربة رملية سلتيه. كانت قصبة المحراث الأول تامة الانحناء، بينما كانت شبه مستقيمة وشبه منحنية للمحراثين الثاني والثالث على التوالي. استخدمت أربع سرعات أمامية وعمقان مختلفان للحراثة وذلك لدراسة تأثيرها على متطلبات القوة الأفقية والرأسية. وقد تم تحديد مواصفات التربة والمحاريث المستخدمة وقياس متطلبات القوة. أظهرت النتائج وجود زيادة معنوية في القوة الأفقية (نيوتن/ قصبة/سم٢) تتناسب طردياً مع السرعة الأمامية للثلاث محاريث. ولم تكن هناك أي زيادة معنوية بالنسبة للقوة الرأسية للثلاث محاريث عند زيادة السرعة الأمامية. وكانت القصبة تامة الانحناء الأكثر متطلباً للقوة مقارنة بالنوعين الآخرين.

ABSTRACT: The horizontal and vertical forces acting on three chisel plows having different shank shapes were measured in a sandy loam soil. The shank shape of the first plow was curved, while those of the second and third plows were semi-straight and semi-curved, respectively. The effect of forward speeds and plowing depth upon the horizontal and vertical force measurements were investigated. Soil characteristics, chisel plow specifications and results of tillage experiments were reported. A significant increase in horizontal force (N/shank/cm^2) was observed for all the three commercial chisel plows and was proportional to the increase in the forward speed. However, non-significant increase in vertical force (N/shank/cm^2) was observed for all the three plows with an increase in the forward speed. The curved shank gave values of horizontal and vertical forces (N/shank/cm^2) greater than that of the other shank shapes.

Keywords: chisel plows, shank shape, sandy loam soil, horizontal and vertical forces.

The availability of horizontal forces or draft requirement data of tillage implements is an important factor in selecting suitable tillage implements for a particular farming system. Farm managers and consultants use draft and power requirement data of tillage implements in specific soil types to determine the proper size of the required tractor.

Using accurate draft data could minimize ownership and operating costs of both agricultural tractors and implements. Farmers mostly depend on past experience for selecting tractors and implements for various farming operations. Large numbers of imported chisel plows are commercially available in local markets of Saudi Arabia. However there is little information available from the manufacturer on the benefits associated with their design aspects. Accordingly the knowledge of the effect of chisel plows design aspects on horizontal and vertical force (the measure of the ground engaging tool's ability to hold itself at the given plowing depth) is important in guiding local manufactures to improve the design of chisel plows.

ASAE standard S414.1 (ASAE, 1994) indicated that a chisel plow could be classified as either a primary or a secondary tillage implement. The plow shatters the soil without complete burial or mixing of surface materials. Multiple rows of staggered curved shanks

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are mounted either rigidly, with spring-cushions, or with spring rests on plow frames. Interchangeable sweep, chisel, spike, or shovel tools are attached to each shank.

Presently, there is a shortage of data on horizontal and vertical forces of chisel plows operating on sandy loam soils. Sandy loam soil is the most common type of soil in the central region of Saudi Arabia.

Published work shows that many studies have been conducted to evaluate the design aspects of chisel plows and others to measure horizontal and vertical forces and required power of tillage implements under various soil conditions (Slattery and Riley, 1997). Du Plessis (1985) showed that when evaluating chisel plow tines, the curved tine shanks performed best when the curve portion was angled back (low rake angle) during the lifting of the stubble. Jorgenson (1988) reported that a curved shank performed better in stubble handling than a vertical set-up.

El-Sayed (1991) selected four types of locally made and imported shanks of chisel plow and ran experiments in clay soil to indicate the effect of shank shape, shank materials, and shank cross-section on draft requirements. He carried-out the tests under different levels of forward speed, plowing depth, and rake angle. He found that the local shank (curved) performed similar to the imported one. Upadhyaya *et al.* (1984) reported that the draft force depended on soil conditions and the geometry of the tillage implement. Erabach *et al.* (1984) reported that shanks that vibrate tend to have better shedding characteristics.

Implement width, plowing depth, forward speeds, tool width, and rake angles are factors that affect horizontal and vertical forces of a tillage implement. The effect of speed on implement draft is further dependant on the soil type and that of the implement. It has been widely reported that the draft forces on implements increased significantly with the forward speed relationship varying from linear to quadratic (Grisso *et al.*, 1994).

Onwualu and Watts (1998) reported that an understanding of the relationship between tool horizontal and vertical forces and forward speed was important in evolving management strategies for optimum performance for the chisel plow. Al-Janobi *et al.* (2000) evaluated three mathematical models predicting horizontal and vertical forces the same plow with different tools when operating on sandy loam soil compared with field measurements. They found that the forces varied according to tool shape, forward speed and plowing depth.

The ASAE standard D497 (ASAE, 1994) presented mathematical expressions for draft and power requirements for tillage implements in several soil types. All draft data presented in the ASAE standards were based on North American soils.

Payne (1956) reported that the draft of a 10 cm wide straight chisel ranged from 9.17 kN at an approach angle of 160° to 1.94 kN at 20°. Al-Janobi and Al-Suhaibani (1998) reported that for four primary tillage implements operating in sandy loam soil, the draft was affected significantly by forward speed and plowing depth. Al-Suhaibani and Al-Janobi (1997) measured the draft of four primary tillage implements in sandy loam soil. They found that the draft varied according to the type of tillage implement.

Our paper discusses the influence of shank shape of three common chisel plows, operating on a sandy loam soil under different levels of forward speed and plowing depth, on horizontal and vertical forces requirements.

Materials and Methods

Experiments were conducted at King Saud University's Agricultural Research and Experimental Farm at Dirab. The soil in the experimental site was sandy loam. There was no crop growth and the field was left fallow. Prior to performing the tillage experiment, the field was irrigated for three days by using a sprinkler irrigation system. Soil from the field was classified by mechanical analysis. Soil samples were collected and weighed during the tillage experiments. Moisture content and bulk density was also determined. The samples were then placed in an electric oven maintained at 110°C for 48 hours. The dried soil samples were reweighed and the moisture contents were calculated on a dry weight basis. Cone index values were obtained by taking penetrometer readings over the implement depth. The cone used was of ASAE standard with a 30° cone angle and a diameter of 2.06 cm.

Three commercial chisel plows of different shank shape were used in this experiment. These implements were representative of the standard primary tillage implements most commonly used for seedbed preparation in Saudi Arabia (Table 1, Figure 1). For each of the three chisel plows, four forward speeds and two plowing depths were used in a combination resulting in a total of 24 treatments. The selected forward speeds and plowing depths used for the three chisel plows are presented in Table 2.

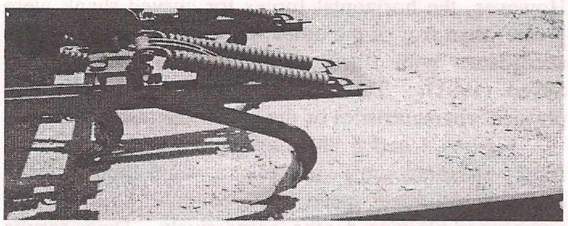
A randomized complete block design experiment was used in the test (3-plow types x 4-speeds x 2-depths). The treatments were randomly distributed in the field test. An experimental block 72 m long by 5 m wide was used for each treatment. A small block of approximately 10 m long by 5 m wide in the beginning of each tested block was used to enable the tractor and implement to reach the required forward speed and plowing depth. Depth was measured as the vertical distance from the top of the undisturbed soil surface to the implement's deepest penetration. During field operations for each chisel plow, the tractor was operated at the same forward speed but at

TABLE 1

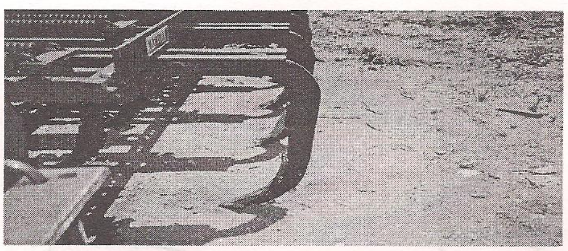
Chisel plow specifications.

Chisel Plow Shank	Total Plow Weight (kN)	Total Plow Width* (cm)	Specifications
Curved	3.73	210	Heavy duty type consisting of 7 completely curved shanks arranged in three rows, 2 in the front, and 2 in the middle row and 3 in the back row. The distance was 120 cm between shanks in front row, 60 cm between shanks in middle row, and 90 cm between shanks in back row. The distance between rows is 71 cm. IH Company (England), model 1-1. Serial No. 603. Width and thickness of shank 5 cm and 2.5 cm, respectively. Shank stem angle 50° and 5 cm width of chisel tool.
Almost straight (semi straight)	4.07	337.5	Heavy duty type consisting of 15 almost straight shanks arranged in two rows. The front and back rows had 8 and 7 shanks, respectively. The distance was 45 cm between shanks in each row and 48 cm between rows. MARZIA Company (Italy), model CMP/15-R. Serial No. 59062. Width and thickness of shank were 5 cm and 2.5 cm, respectively. Shank stem angle was 51° and width of chisel tool was 6 cm.
Almost curved (semi curved)	6.67	300	Heavy duty type consisting of 15 almost curved shanks arranged in two rows. The front and back rows had 7 and 8 shanks, respectively. The distance was 40 cm between shanks in each row and 51 cm between rows. GALUCHO Company (Portugal), model STT-15. Serial No. G99 – 343499. Width and thickness of shank were 5 cm and 2.5 cm, respectively. Shank stem angle was 42° and width of chisel tool was 6 cm.

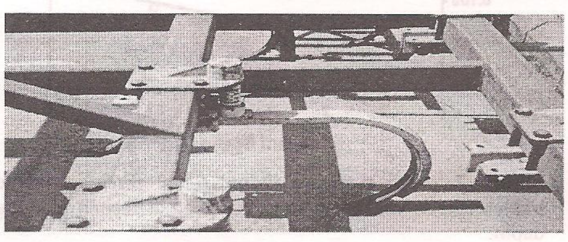
* Theoretical width.



Semi Curved Shank



Semi Straight Shank



Curved Shank

Figure 1. Different shank shapes of three commercial chisel plows used in experiments.

different plowing depths. The statistical package SAS (SAS, 1986) was used in the analysis of data. One way analysis of variance (ANOVA) test was adopted to measure the force significance among plows, speeds, and plowing depths according to the method of Steel and Torrie (1960).

A tractor with 75.1 kW at 2196 rpm and in good condition was used in all the experiments. The implement horizontal and vertical forces, plowing depth and tractor forward speed during field operations were measured and recorded by an onboard datalogger in the tractor cab. The instrumentation system consisted of a datalogger, a three-point linkage dynamometer, a depth position transducer, and a fifth wheel. The three-point linkage dynamometer used to measure implement horizontal and vertical forces was calibrated prior to the experiments using a specially built calibration rig. The complete description of the instrumentation system and the calibration of transducers are given by Al-Suhaibani *et al.* (1994) and the details of three point linkage – implement force calculations are shown in Al-Janobi (2000).

A performance test program was developed and documented for the datalogger to scan the transducers every second during field operation. Therefore, the number of readings made in each treatment depended on the forward speed of the tractor. The minimum number of readings taken in each experiment was 25.

To begin the field tests, the three-point height lever was operated to lower the implement corresponding to the plowing depth. Then the tractor was accelerated to the required operating speed with a known gear range before entering the first test block. Data acquisition was

TABLE 2

Average and standard deviation of forward speeds and plowing depths used in the experiments.

Curved shank				Almost straight shank				Almost curved shank			
Forward speed (km/h)		Plowing depth (cm)		Forward speed, (km/h)		Plowing depth (cm)		Forward speed, (km/h)		Plowing depth (cm)	
Avg*	Sd+	Avg*	Sd+	Avg*	Sd+	Avg*	Sd+	Avg*	Sd+	Avg*	Sd+
2.83	0.04	7.44	0.04	2.81	0.08	8.35	0.05	2.71	0.13	9.76	0.04
4.76	0.06	7.06	0.25	4.70	0.04	8.36	0.04	4.44	0.11	9.14	1.54
5.95	0.05	7.31	0.17	5.71	0.15	8.38	0.06	5.33	0.13	9.68	0.11
6.92	0.09	7.10	0.16	6.59	0.13	8.46	0.11	6.34	0.19	9.59	0.16
2.71	0.08	17.13	1.78	2.66	0.03	12.34	0.04	3.33	0.06	12.57	0.65
4.58	0.10	15.92	0.17	4.21	0.26	12.16	0.40	4.46	0.06	12.70	0.17
5.48	0.12	16.00	0.13	5.16	0.17	11.62	0.04	5.44	0.09	12.44	0.28
6.39	0.15	15.98	0.15	5.93	0.17	11.72	0.06	6.26	0.11	12.44	0.18

*Average. +Standard deviation.

activated by pressing the push button switch on the activity unit as the tractor passed the flag marking the beginning of the first test block. Data acquisition continued until the end of the test block. After finishing the first test block, the tractor was again driven straight toward the second test block with a different forward speed and the process was repeated. The same procedure was repeated for the second and third chisel plows.

Due to different plowing depths, different plowing theoretical width, and different number of shanks, the horizontal and vertical forces were divided by the cross-sectional area of the tilled zone and number of shanks. The statistical description, average and standard deviations values for forward speeds and plowing depths of all the tillage implements during the tillage experiments are given in Table 2.

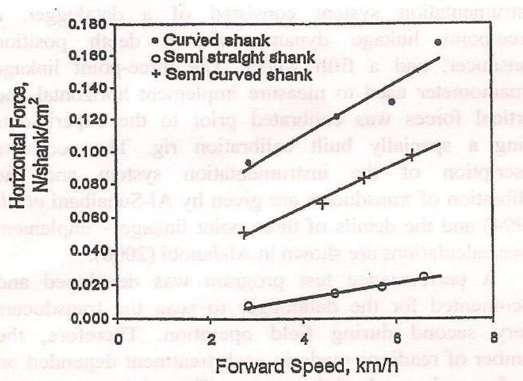


Figure 2. The response in horizontal force of tillage implements to change in forward speed at first plowing depth.

Results and Discussion

The response of horizontal force (N/shank/cm^2) of tillage implements as affected by changes in travel speed for three chisel plows at first and second plowing depths are illustrated in Figures 2 and 3, respectively. These results showed an increase in horizontal force in all the treatments proportional to the increase in forward speed. However, the horizontal forces for curved shank were greater than that of the other shanks. This result was in accordance with Harrigan and Rotz (1994) and El-Sayed (1991). Table 3 shows average texture and physical characteristics of the soil at the test site.

Figures 4 and 5 illustrate the response of vertical force (N/shank/cm^2) of tillage implements when changing the travel speed for three chisel plows at first and second plowing depths, respectively. These results

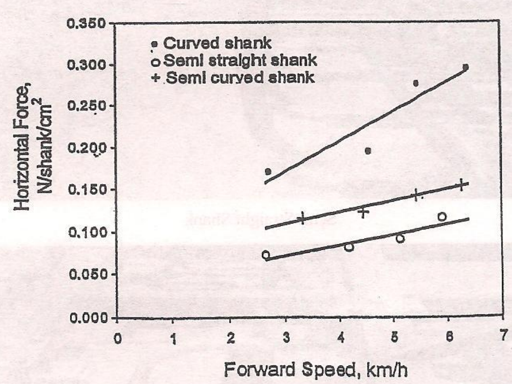


Figure 3. The response in horizontal force of tillage implements to change in forward speed at second plowing depth.

TABLE 3

Average texture and physical characteristics of the soil at the test site.

Characteristics	Size Range (mm)	Test Site
Soil content⁺		
Sand	0.50 -0.25	80 %
Silt	0.05-0.002	11 %
Clay	< 0.002	9 %
Soil classification	-	Sandy loam
Physical properties	-	
Bulk density*	-	1.38 g/cm^3
Moisture content*, db	-	7.34 %
Cone index*	-	26 N/cm^3

⁺The soil texture characteristics were measured by mechanical particle analysis.
*At depth 0 to 10 cm.

showed a slight increase in vertical force in all the treatments relative to increasing the forward speed. This result agreed with that obtained by Onwualu and Watts (1998). The vertical forces for the curved shank were higher than the other shanks, probably due to the lesser width of plowing of the curved shank compared with the other two plows.

Figures 6 and 7 show the effect of shank shape on horizontal forces at first and second plowing depth, traveled at different forward speeds. At the fourth forward speed, the horizontal force was 0.167 N/shank/cm^2 for curved shank, while it was 0.024 and 0.098 N/shank/cm^2 for the almost-straight and almost-curved shank shape at the first plowing depth, respectively. It can be concluded that the curved shank gave a horizontal force 86 and 41% higher than the almost-straight and almost-curved shank shape, respectively, at first plowing depth.

The effect of shank shape on vertical forces at first and second plowing depth is shown in Figures 8 and 9, respectively. It can be seen that the curved shank gave a higher vertical force compared with the other two shanks when the implements traveled at different forward speeds. At the fourth forward speed, the vertical force was about 0.392 N/shank/cm^2 for curved shank, while it was 0.112 and 0.173 N/shank/cm^2 for the almost-straight and almost-curved shank shape, respectively, at the first plowing depth. From this we can determine that the curved shank required a vertical force 71% and 56% greater than the almost-straight and almost-curved shank shape, respectively, at first plowing depth.

Linear regression was performed on the measured values of horizontal and vertical forces of all implements. The regression equation that gave good fit with a maximum coefficient of regression, r^2, and variables that have significant effect on the horizontal and vertical forces (Table 4) of all implements can be written in the following form:

$$UD = A + B * S \qquad (1)$$

where UD is the horizontal or vertical force (N/shank/cm^2); S, is the forward speed, km/h.; and A and B are the regression coefficients.

The linear effects of forward speed agreed with the data presented by Harrigan and Rotz (1994). Equation (1) was utilized to predict horizontal and vertical force for chisel plows tested on sandy loam soil within the ranges of speed and depths used. The least square fit with an r^2 ranging between 0.870 to 0.986 indicated that the horizontal and vertical forces can be predicted with some success for each of the implements tested.

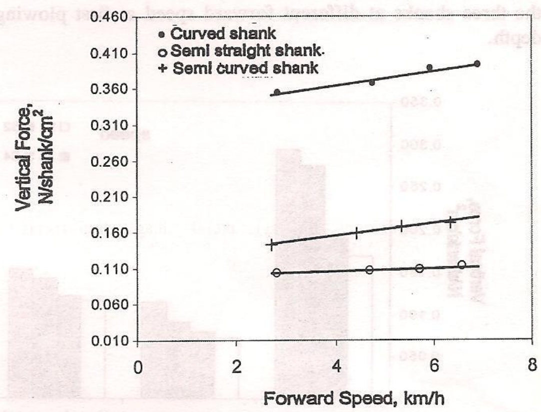


Figure 4. The response in vertical force of tillage implements to change in forward speed at first plowing depth.

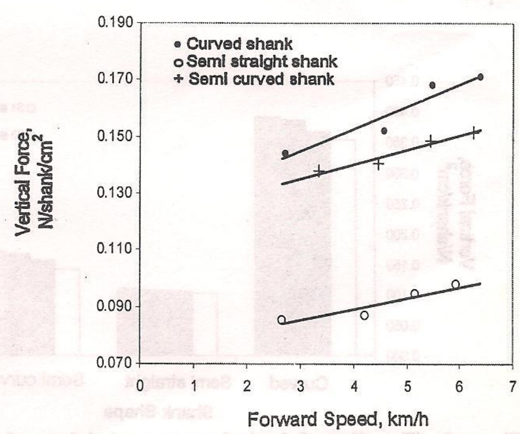


Figure 5. The response in vertical force of tillage implements to change in forward speed at second plowing depth.

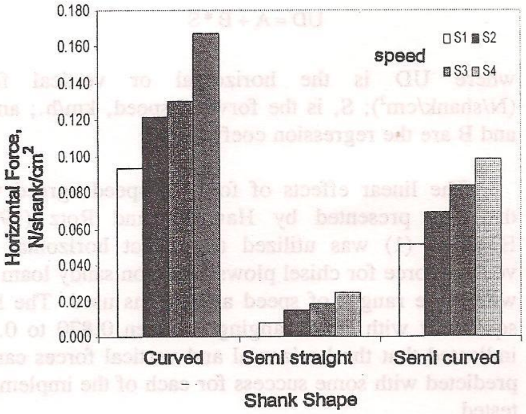


Figure 6. The effect of shank shape on horizontal force of the three shanks at different forward speed at first plowing depth.

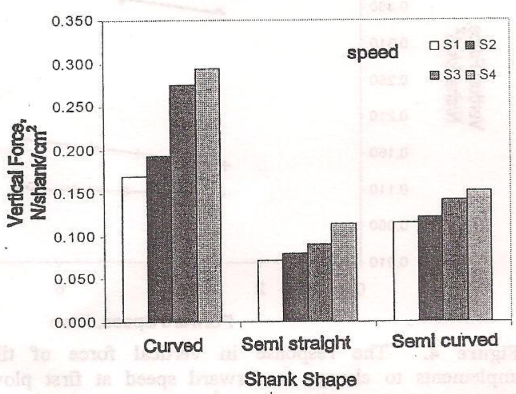


Figure 7. The effect of shank shape on horizontal force of the three shanks at different forward speed at second plowing depth.

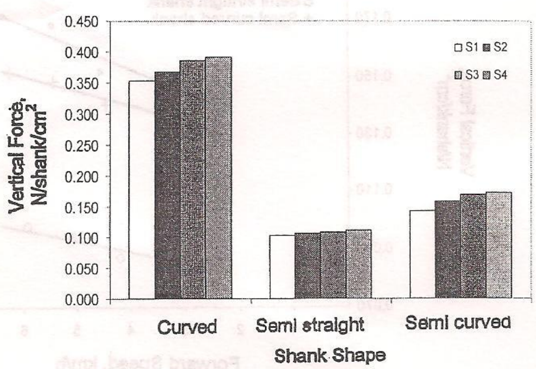


Figure 8. The effect of shank shape on vertical force of the three shanks at different forward speed at first plowing depth.

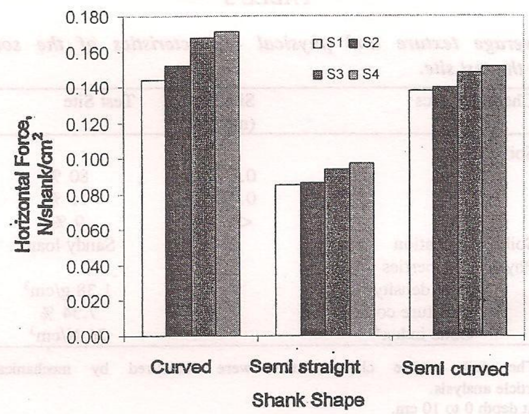


Figure 9. The effect of shank shape on vertical force of the three shanks at different forward speed at second plowing depth.

TABLE 4

Regression coefficients and coefficient of determination for horizontal force (draft), (N/shank/cm²) according to equation (1).

Shank Shape	A		B		R^2	
	d1	d2	d1	d2	d1	d2
Curved	0.044	0.059	0.017	0.036	0.914	0.870
Semi straight	-0.005	0.035	0.004	0.012	0.978	0.842
Semi curved	0.014	0.067	0.013	0.014	0.986	0.962

For Vertical Force

Shank Shape	A		B		R^2	
	d1	d2	d1	d2	d1	d2
Curved	0.325	0.121	0.010	0.008	0.956	0.913
Semi straight	0.097	0.073	0.002	0.004	0.931	0.865
Semi curved	0.120	0.120	0.009	0.005	0.982	0.944

d1 = first plowing depth.
d2 = second plowing depth.

Conclusions

An increase in horizontal and vertical forces was observed for all three tillage implements with an increase in the forward speed and plowing depth. The curved shank gave a higher horizontal and vertical force compared with the other two shanks when the implements traveled at different forward speeds. The prediction equation of horizontal and vertical force for chisel plows with different shank shape showed that these forces can be predicted with reasonable accuracy for all implements tested.

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