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The Effect of Geometry and Motion Characteristics of Narrow Tillage Tool on Soil Disturbance Efficiency

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Abstract: Tillage operation is one of the most energy – consumer operations in the process of crop production. Narrow tillage tools are vastly used in chisel plow, field cultivators, and subsoilers. Many efforts have been done to apply narrow tillage tools at suitable condition to minimize energy consumption and maximize soil disturbance efficiency. The present study was conducted to observe the effects of aspect ratio, rake angle and speed on draft and vertical forces, soil disturbed area and soil loosening efficiency. The effects of blade rake angle (at four levels 10, 15, 20 and 25 deg), travel speed (at three levels 1.5, 3 and 4.5 km/h) and aspect ratio (at three levels 1.5, 2 and 3) on draft and vertical reaction forces of the Chisel Plow were investigated. Experiments were conducted in loamy soil with 14% moisture. Results revealed that in 5 and 10 cm blade width the effects of aspect ratio, rake angle and speed on draft and vertical forces, soil disturbed area and soil loosening efficiency were highly significant ($P < 0.01$). The highest soil loosening efficiency for 5 cm blade width was observed at the aspect ratio 3, rake angle 15 (degree) and speed 1.5 (km/h). however, result showed that soil loosening efficiency for 10 cm blade width was obtained at aspect ratio 2, rake angle 15 (degree) and 1.5 (km/h). Result showed that soil loosening efficiency is highly depended on blade width.
Key words: Narrow tillage tool, soil disturbance efficiency, draft force

INTRODUCTION

The use of the chisel plough for primary and secondary cultivation has increased considerably in recent years specially as a tool for conservative tillage. With its increasing use, there have been numerous investigations of the interaction between tine and soil both in respect of the rupture of soil and of soil forces. Design of narrow soil cutting tine is usually based on Mechanics theories. In order to have the applied design, the designers should know the nature of soil tillage tool interactions. It is important to have a fundamental understanding of the nature of soil failure together with the factors affecting it and the conditions under which it occurs. Usually the blade geometry (working depth and width, rake angle, aspect ratio and etc) and the motional charachteristics of tillage tine (speed and acceleration) are an important factors affecting on soil failure and the energy use.

Changing in the geometry and motional characteristics of tillage tool can directly affect on field capacity. One of the main aims of a good farm manager is to prepare the soil for planting in the shortest possible time. This can be accomplished by maximizing the field capacity of the tillage implement. The field capacity, which is the rate of field coverage, is the product of the width and speed of operation. The choice is, therefore, between operating large equipments at low speed or smaller equipments at higher speed. In making this decision, the relationship between tool force and speed must be known.

The effects of blade aspect ratio and blade rake angle on draft force have been reported by many scholars (Mckyes, 1989; Mckyes and Ali, 1977; McKyes and Maswaure, 1997; Payen, 1956).

The relationship between draught and speed has been reported as linear, second-order polynomial, parabolic and exponential (Rowe and Barnes, 1961; Siemens et al., 1965; Stafford, 1979; Swick and Perumpral, 1988; Gupta et al., 1989; Owen, 1989).

These differences occur as a result of the inertia required to accelerate soil, effect of shear rate on shear strength and effect of shear rate on soil-metal friction, all of which vary with soil type and condition. For example for sandy soils, the effect of the inertial forces is more significant. Since inertial forces increase as the square of the speed, draught increases as the square of the speed for such soils (Terpstra, 1977; Owen, 1989). For clay soils, the effect of shear rate on shear and adhesive strength is more significant (Rowe and Barnes, 1961; Wismer and Luth, 1972). For such soils, draught increases exponentially with speed (Stafford, 1979).

Although numerous studies conducted in this area, but the authors have to do this study because of variation of results depending on soil texture and mechanical parameters. The aims of the present study was to investigate the effects of blade rake angle, blade aspect ratio and blade forward speed on the draft and vertical reaction forces. Also determining the highest soil disterbance effucuency is considerable.

Figure 1. The tines used in the study

Figure 2. Blade rotation mechanism to achieve desired rake angle

MATERIALS and METHODS

Two tines: T1 (5 cm width), T2 (10 cm width) were used in this study (Fig. 1). The tines were made from 10 mm flat plain carbon steel (DF2 steel based on ASABE standard). Each blade was worked at four rake angle (10°, 15°, 20° and 25°) by rotating the blade shank with resoect to tool carriage of soil bin around the horizontal axix normal to travle direction (Fig. 2). The blades were designed as curve type. Each blade was working in three depth to with ratio or aspect ratio (1.5, 3, 4.5). in order to investigate the effect of travle speed each blade was worked on three travle speed (1.5, 3 and 4.5 km/h).

Experiments were conducted in the Soil Dynamics Laboratory of the Agricultural Engineering research institute,Karaj ,Iran. The soil bin facilities consisted of an indoor soil bin of 24 m length, 1.7 m width and 1 m depth; The soil bin consist of soil box, tool carriage mechanisem, power transmission mechanisem and soil processing system). The tool carriage consisted of an electeromotor connected to the gearbox to provide the lateral displacement of the tool and a hydrilic cylinder to provide the working depth. The tool carriage was pulled by MF 399 tractor with constant speed.

The soil filled in the box every 5 cm thickness layers and compacted to desired level to achive the 1.45gr/cm3 soil bulk density. In order to ensure uniformity of soil compaction, the soil cone index was measured after each filling stage using "Eijkelkamo 06.15 "soil penetrometer. The soil studied was loamy soil (33.28% sand, 45.84% silt, and 20.88% clay), according to the USDA textural classification of soils. The soil moisture content was kept on 14% dry basis.

In order to measure the draft and vertical reaction forces of tillage tool an octagonal dynamometer was used (Fig. 3). This dynamometer can measure the forces anf moments in three directions. 12 strain gauges were installed on the aluminum frame and the strain gauges were connected to each other to organize three Wetson bridge (fig4). The dynamometer was calibrated and the force data were collected using CR23X micro logger.

Figure 3. the octagonal ring transducer connected to the tool carriage

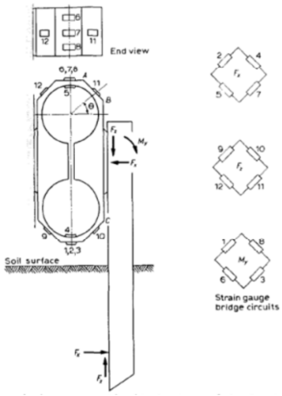

Figure 4. Schematic view of strain gauges connection and Wetson bridge formation.

In order to measere the soil disturbed area and determine the form of rupture plain, a profile meter was designed and used. This device consisted of two 60 cm length ruller in which the 3 mm diameter holes were built on the rullers every 10 mm. The long steel rods were placed in to the holes. The function of the bars is determining the depth of broken and loosened soil.

The horixontal draft force, vertical reaction force and the soil disturbed area were measured for each treatments. The area of soil disturbed was divided by draft force to calculate the soil disterbance efficiency (SDE). This efficiency determine the ability of tool in failing he highest soil with lowest force. Usually farmers interested in having the tools with high soil disturbance efficiency.

The effects of blade rake angle, blade aspect ratio and forward speed on draft and vertical force and soil disturbence efficiency were investigated using factorial test and complate block design. The comparison of the mean were done using Duncan's multiple range test.

RESULTS and DISCUSSION

As indicated by Table 1, the draft and vertical force obtained from 5 cm width blade was highly affected by rake angle, blade aspect ratio and tine forward speed ($P < 0.01$). The interaction between mentioned factors did not have significant effect on draft and vertical force. This means that the above factors can affect the reaction forces indipendently. So changing in each mentioned factors can make change in the reaction force. Analysis of variance showed that the indipendent variables have significant effect on soil disturbed area and soil disturbance efficiency. The SDE is highly affected by the interaction of the factors. The similar results was seen when the width of blade increase to 10 cm as indicated by Table 2.

Table 1. Analysis of variance for draft and vertical forces, soil disturbed area and soil disturbance efficiency for 5 cm blade width

Source	F value		Vertical force	Soil disturbed area	SDE
	df	Draft force			
Rake angle (A)	3	457.2**	19.85**	73.34**	211.84**
Aspect Ratio (B)	2	2883**	242.39**	28420**	199.33**
Forward speed (C)	2	807.93**	260.84**	751.97**	190.82**
A×B	6	0.69 ns	0.161 ns	58.41 **	10.51 **
A×C	6	0.037 ns	0.618 ns	16.33 **	10.18 **
B×C	4	1.503 ns	0.632 ns	6.18 **	5.93 **
A×B×C	12	0.119 ns	0.142 ns	23.56 **	1.35 ns

** Significant at $P < 0.01$; ns Non significant at 5% risk level.

Table2. Analysis of variance for draft and vertical forces, soil disturbed area and soil disturbance efficiency for 10 cm blade width

Source	F value		Vertical force	Soil disturbed area	SDE
	df	Draft force			
Rake angle (A)	3	32.22**	176.37**	2966**	63.35**
Aspect Ratio (B)	2	2195**	1589**	227000**	158.41**
Forward speed (C)	2	323.55**	218.06**	4335**	195.79**
A×B	6	1.75 ns	28.78 **	820.56 **	4.51 **
A×C	6	0.409 ns	0.216ns	46.14 **	8.50 **
B×C	4	16.66 **	2.58 *	239.1 **	18.26 **
A×B×C	12	0.416 ns	1.68 ns	71.22 **	2.15 *

* Significant at $P < 0.05$; ** Significant at $P < 0.01$; ns Non significant at 5% risk level.

The comparison of the means for draft force showed that with increasing in blade rake angle from 10° to 25° the draft force decreases at first and then increased so that the minimum amount of draft force was seen at 15° rake angle and the maximum was seen at 25° rake angle (Figures 5 and 6). Theoretically when a simple tine works in the zero rake angle, the draft force will approach to infinity (Payen, 1956). This is the main reason for more draft force when the blade has worked at 15° rake angle than 10° rake angle. Comparison of the means for draft force showed that there was a parabolic relation between draft force and blade rake angle when the 5cm width blade was tested. The similar results were observed when 10cm width blade was tested.

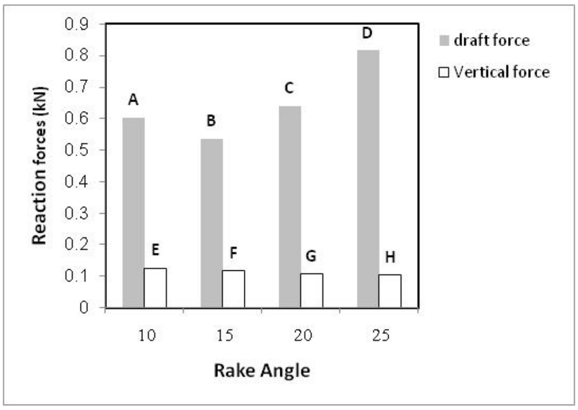

Figure 5. Effect of blade rake angle on reaction forces of 5cm width blade

Aspect ratio is one of the most important parameters that affect on draft force. Comparisons of the means for draft force as affected by tine aspect ratio showed that increasing in aspect ratio causes an increase in draft force. The linear relation between draft force and aspect ratio was seen when 5 cm blade was considered while the exponential relation was seen for 10 cm width blade. It is obvious that when a simple tillage tool works below the critical depth, increasing the working depth and increasing in aspect ratio will increase the draft force.

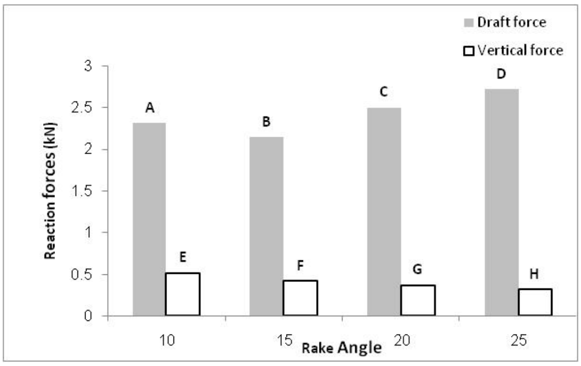

Figure 6. Effect of blade rake angle on reaction forces of 10cm width blade

The effect of forward speed on draft force was investigated. Results showed that the forward speed had direct relation with draft force. The linear relation between forward speed and draft force were seen for both 5 cm and 10 cm width blades (Figures 7 and 8).

The comparison of the means for vertical reaction force as affected by rake angle, aspect ratio and forward speed were done. Results revealed that there is an inverse relation between rake angle and vertical force (power relationship) for both blades (figures 5 and 6). The direct linear relation was seen between aspect ratio and vertical force and also between forward speed and vertical force (Figures 7 and 8). The comparison of the means showed that in order to apply the minimum upward vertical force, the blade should work at lowest aspect ratio (1.5) and lowest forward speed (1.5 km/h).

The area of soil disturbed was highly affected by blade rake angle, aspect ratio and forward speed. Comparison of the means for soil disturbed area showed that this area will increase when the aspect ratio of tine increase. Also results indicated that the forward speed of blade had linear direct linear effect on the area of soil disturbed.

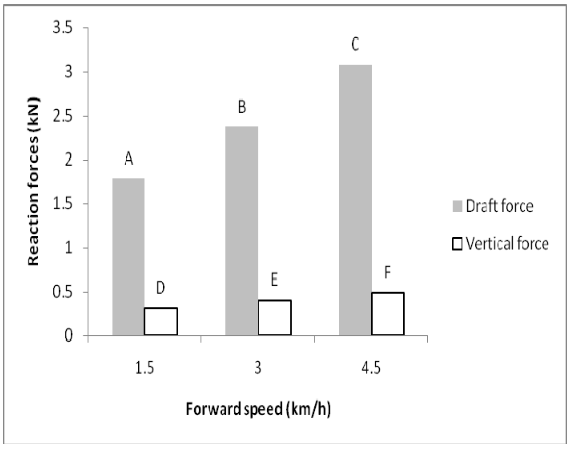

Figure 7. Effect of forward speed on reaction forces of 5 cm width blade

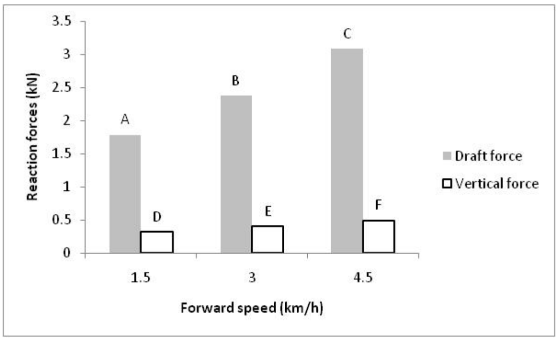

Figure 8. Effect of forward speed on reaction forces of 10 cm width blade

As mentioned before the soil disturbance efficiency (SDE) is an important criterion to select the working condition of tillage tool. When the SDE of tine A is more than tine B, the first tine can disturb more cross sectional area with draft force. The comparisons of the mean for SDE as affected by blade rake angle for 5cm width blade showed that the highest amount of SDE was seen at 15° rake angle. The second order relation between SDE and rake angle dictated that the SDE is very low when the blade is working in 10° and 25° rake angle. The inverse relation between SDE and forward speed was observed. The ascending relation between aspect ratio and SDE advised that the highest SDE was achieved when the blade works in aspect ratio3. The highest amount of SDE was observed at aspect ratio 2, when the 10 cm width blade was operated in the soil.

CONCLUSIONS

The effects of blade rake angle (at four levels 10, 15, 20 and 25 deg), travel speed (at three levels 1.5, 3 and 4.5 km/h) and aspect ratio (at three levels 1.5, 2 and 3) of a single simple tine on draft and vertical reaction forces were investigated. Experiments were conducted in soil bin with loamy soil at 14% moisture. Results revealed that in 5 and 10 cm blade width the effects of aspect ratio, rake angle and speed on draft and vertical forces, soil disturbed area and soil loosening efficiency were highly significant ($P < 0.01$). the relation between rake angle, forward speed and aspect ratio with respect to reaction forces, soil disturbed area and soil disturbance efficiency were obtained and reported as linear, parabolic and power relation. The highest soil loosening efficiency for 5 cm blade width was observed at the aspect ratio 3, rake angle 15 (deg) and speed 1.5 (km/h). however, result showed that soil loosening efficiency for 10 cm blade width was obtained at aspect ratio 2, rake angle 15 (deg) and 1.5 (km/h). Result showed that soil loosening efficiency is highly depended on blade width.

REFERENCES

Gupta, P.D., Gupta, C.P., Pandey, K.P., 1989. An analytical model for predicting draft forces on convex-type cutting blades. Soil and Tillage Research. 14, 131-144.

McKyes, E., Ali, O.S., 1977. The cutting of soil by narrow blades. Journal of terramechanics . 14, 43–58.

McKyes, E., 1989. Soil cutting and tillage, Elsevier Science Publishing Company INC.

McKy es , E ., Maswaure, J., 1 99 7. Effect of design parameters of flat tillage tools on loosening of clay soil. Soil and Tillage Research. 4 3, 195–204.

Payne, P.C.J., 1956. The relationship between mechanical properties of soil and the performance o f simple cultivation implements. Journal of Agricultural Engineering Research. 1, 23–50.

Rowe, R.J., Barnes, K.K., 1961. Influence of speed on elements of draft of a tillage tool. Transaction of ASAE. 4, 55-57.

Siemens, J.C., Weber, J.A., Thornburn, T.H., 1965. Mechanics of soil as influenced by model tillage tools. Transaction of ASAE. 8(1), 1-7.

Stafford, J.V., 1979. The performance of a rigid tine in relation to soil properties and speed. Journal of Agricultural Engineering Research. 24, 41-57.

Swick, W.C., Perumpral, J.V., 1988. A model for predicting soil tool interaction. Journal of Terramechanics. 25(1), 43-56.

Owen, G.T., 1989. Subsoiling forces and tool speed in compact soils. Canadian Agricultural Engineering. 31(1), 15-20.

Terpstra, R., 1977. Draught forces of tines in beds of glass spheres. Journal of Agricultural Engineering Research. 22, 135-143.

Wismer, R.D., Luth, H.J., 1972. Performance of plane soil cutting blades in a clay. Transaction of ASAE. 15(2), 211-216.