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Effects of Design Parameters of a Cultivator Share on Draft Force and Soil Loosening in a Soil Bin

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Abstract: This experimental study was performed with the aim to evaluate effects of design parameters of a cultivator share on draft force and soil loosening in a soil bin. The test tool variables included rake angle to the horizontal of 12.5, 17.5 and 22.5°, working depths of 70, 110 and 150 mm and forward velocity of 1.08, 1.55 and 2.08 m sec^{-1}. Measurements were taken of draft force and disturbed area of soil by the cultivator share. The resulting draft force was increased with increasing rake angle, forward velocities and working depth. The draft force in different trials varied from 42 to 202.5 daN. The area disturbed of soil was larger when tool rake angle, forward velocity and working depth were increased. The greatest disturbed area occurred at rake angle of 22.5°, forward velocity of 2.08 m sec^{-1} and depth of 150 mm. The soil loosening increased with rake angle and forward velocity but loosening decreased with increased working depth. The soil loosening varied from 21.07 to 40.45%.

Key words: Cultivator share, soil loosening, disturbed area of soil, draft efficiency

INTRODUCTION

Soil tillage aims are the control of weeds, incorporation of organic matter into the soil and improvement soil structure. Tillage at optimum tool geometry and working conditions will also minimise the number of subsequent tillage operations required. Therefore, the total energy input for a given tillage system will decrease. For reducing tillage operations, it is important to know the draft requirements for different tool geometry.

Primary and secondary soil manipulation is the basic operation required for cultivation of any kind of crop. Soil manipulating tools should withstand adverse field conditions, such as the presence of a hardpan, small rocky formations, stumps and stubble, during soil engagement without failure. Soil working tools such as mouldboard ploughs, disc ploughs and ridgers have long been accepted and successfully used by farmers under average field conditions. The duck foot sweep is another kind of soil engaging tool that is popular amongst farmers for secondary field operations because of its large wing width, which causes better coverage of soil manipulation between two furrows. Owing to their large soil engaging surface area and long cutting edges, sweeps in general are subjected to high tillage forces. They are also exposed to severe abrasion and corrosion while manipulating sandy, acidic and alkaline soils (Gupta *et al*., 2004).

Seedbed preparation greatly contributes towards the overall cost of farm operations, implying that significant savings are possible through optimized design and development of tillage machinery. Agricultural tools have for a long time been designed on a trial and basis as the soil-tool interactions involved have not been well defined and quantified. More research needs to be conducted to clearly understand the mechanics of soil under the influence of agricultural tillage tools (Makanga *et al*., 1997).

Owen (1989) studied the effect of subsoiler speed on forces and soil disturbance in clay loam and compact sandy loam soils. The tool speed had highly significant linear effects on the vertical force and highly significant quadratic effects on the horizontal force, total force, moment and specific resistance.

The effect of force on furrow openers having different rake angles was studied by Dransfield *et al*. (1964), Siemens *et al*. (1965), Abernathy and Porterfield (1969), Gebresenbet and Johnson (1992), Mathur and Pandey (1992) and Damora and Pandey (1995). The convention used to represent rake angle varied; however, if rake angle is denoted by the angle which the furrow opener makes with the horizontal in the direction of travel, then the general conclusion is that both horizontal and vertical forces increase with increased rake angles. Siemens *et al*. (1965) concluded analytically as well as from experimental results that a rake angle of 25° gave the

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lowest draft. The rake angle of the furrow opener which gave minimum specific draft was reported by Mathur and Pandey (1992) as 28° for a lateritic sandy clay loam.

Most of studies on performance evaluations of secondary tillage have been done in field conditions. Little research has been done on cultivator share geometry in soil bins. Therefore, the primary objective of this study was to examine effects of rake angle, working depth and forward velocity on draft force, disturbed area of soil, soil loosening and draft efficiency in a soil bin.

MATERIALS AND METHODS

This study was conducted under controlled conditions in a soil bin at the Department of Agriculture Machinery, Faculty of Agricultural, Selçuk University in Turkey, 2007. The soil bin used in these tests was 20×2.25×1 m dimension. The soil bin facilities, constructed for testing of agricultural implement have been described in detail by Çarman and Doğan (2000). The test machine moves on rails by means of chain-gear driven with an electric motor. The cultivator share has been connected as without stage adjustable on vertical planes to the front of the test machine (Fig. 1).

The construction details of cultivator shares (duck foot) are shown (Fig. 2). The width (W) and cutting angle (γ) of cultivator shares are constant as 280 mm and 36°, respectively. The test cultivator shares variables included rake angles (α) to the horizontal of 12.5, 17.5 and 22.5°, working depths (d) 70, 110 and 150 mm and forward velocity (V) 1.08, 1.55 and 2.08 m $\sec^{-1}$. The cultivator shares were tested in the soil bin using a completely randomized factorial (3×3×3) experiments unit three replications.

Measurements were taken draft, disturbed soil cross sectional profiles and the initial area of soil disturbed by the cultivator shares. The draft was measured by a horizontal dynamometer connecting the analog amplifier and digital data logger. On each speed, one hundred reading of draft were taken regular intervals and these results were averaged by data logger. Immediately after each speed, three replicates of disturbed soil cross sectional profile were photographed. Then for each cross section the area of original soil cut (Ao) and the resulting total area of disturbed soil (Af) were estimated by plotting the measured coordinates of the cross sections areas using the Sigma Scan Pro5 computer package. Soil loosening (%) values were found using the following formula (McKeys and Maswaure, 1997);

$$\text{Soil loosening} = \frac{Af - Ao}{Af}$$

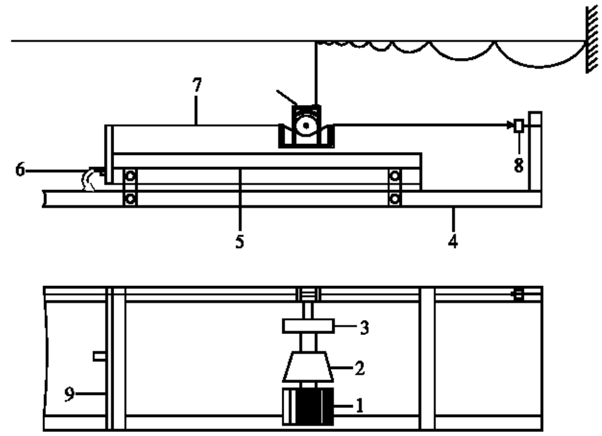

Fig. 1: The details of the experimental set up, 1: Electric motor, 2: Velocity box, 3: Reductor, 4: Rail, 5: Trolley, 6: Cultivator share, 7: Chain-gear, 8: Dynamometer, 9: Adjustable depth mechanism

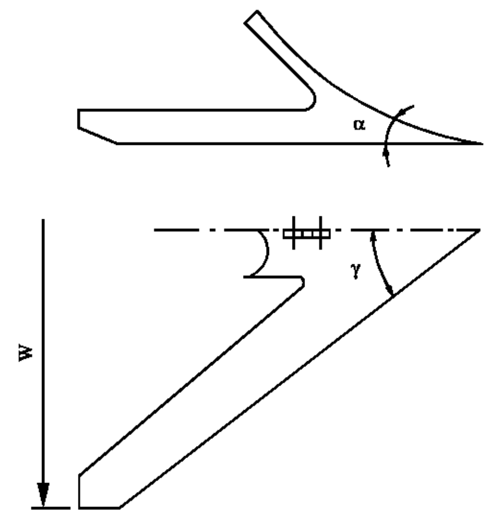

Fig. 2: Technical properties of cultivator share

The effect of rake angles, working depths and working velocity on the depending variables were investigated. In statistical analyses, three factors of design of ANOVA were tested (Larsen and Marx, 1981).

The soil bin was filled with a 0.5 m thick layer of clay loam. Physical and mechanical properties of the soil are as shown (Table 1). The soil surface was leveled with a smoothing shovel that had been connected to the rear of test machine before each trial and then the soil compacted by a heavy flat roller loaded at 0.52 daN to unit area (cm^2).

A soil penetrometer, with a cone angle of 30° and cone diameter of 12.83 mm, was used to determine initial

Table 1: Initial properties of the clay loam used in the soil bin study

Parameters	Mean value
Particle size distribution	
Sand	380 g kg^{-1}
Silt	270 g kg^{-1}
Clay	350 g kg^{-1}
Moisture content	142 g kg^{-1}
Specific gravity	2.63 Mg m^{-3}
Bulk density	1.51 Mg m^{-3}
Cohesion	7.50 kPa
Angle of internal friction	31.85°
Penetration resistance	1500 kPa

soil penetration resistance. It was pushed by hand into the soil to a depth of 200 mm and penetrometer resistance for each 1 cm depth interval was drawn on paper. The values obtained at over the depth range of 200 mm were used as a mean of penetration resistance (Çarman, 1997).

In order to determine initial soil bulk density, soil cores were collected using stainless steel rings with a cutting edge (40 mm diameter, 40 mm length) at a depth range of 0-100 and 10-200 mm. Each core was dried to constant weight at 105°C and bulk density was calculated by the ratio of oven dry mass of soil to ring volume (50 cm^3). The values obtained at the two different depth ranges were used as a mean of bulk density (Black, 1965).

To determine the cohesion and the angle of internal friction of the soil, the direct shear box were used which composed of two metal rings, having circular opening (McKyes, 1985).

RESULTS AND DISCUSSION

Draft force: The average measurements of draft, for each tool rake angle, forward velocity and depth are shown in Fig. 3. The draft force was increased with increasing rake angle, forward velocity and depth. The draft force in different trials varied from 42 to 202.5 daN.

The effects of tool rake angle, forward velocity and depth on draft force were significant ($p<0.01$). As expected, the greatest draft force was observed at a rake angle of 22.5°, forward velocity of 2.08 m sec^{-1} and depth of 150 mm. For an increase of approximately 80% in rake angle, draft force increased about 46%.

The forward velocity at which a tillage implement is pulled through the soil usually has a relatively small influence on draft within the practical range of field working velocities (Stafford, 1979; Collins and Fowler, 1996). Increased velocity produced a small but significant linear increase in draft in the present study.

The greatest variation in draft force occurred as depending on working depth. Approximately, to double the operation depth resulted in a draft force increase of

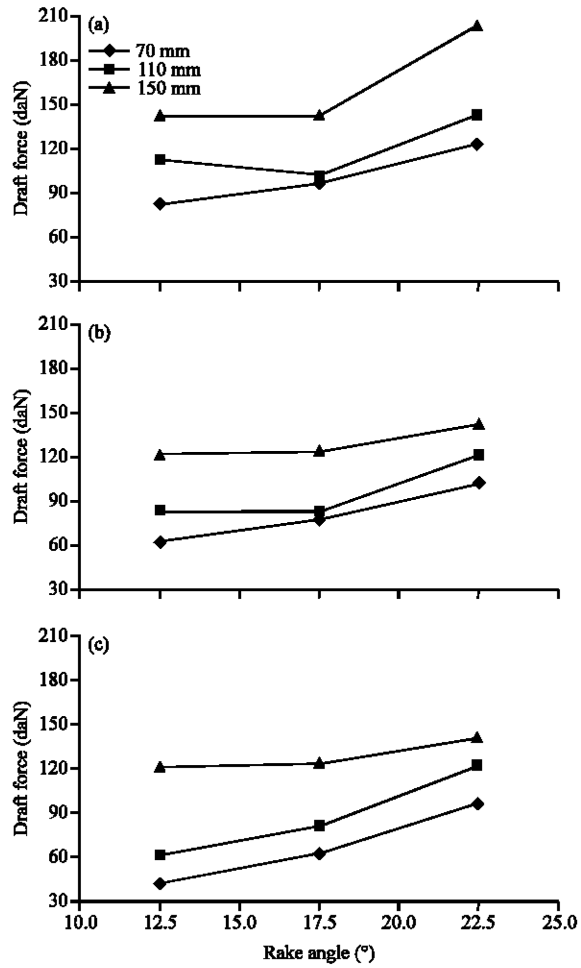

Fig. 3: The effect of rake angle on draft force, (a) V: 2.08 m sec^{-1}, (b) V: 1.55 m sec^{-1} and (c) V: 1.08 m sec^{-1}

75%. Polynomials have provided the best description of this relationship for tillage depths that range from 80 to 300 mm (Kiss and Bellow, 1981; Payne, 1956). However, linear equations ($Y = 29.89 + 0.71$ d; $R^2 = 0.92$) provided good fits to the data for the 70-150 mm soil depths considered in present study.

Disturbed area of soil: It shows the soil area disturbed on a cross section as related to rake angle, forward velocity and working depth (Fig. 4). Disturbed area of soil varied from 319.18 to 970.74 cm^2. As expected, the area of soil disturbed was larger when tool rake angle, forward velocity and depth were increased. The smallest percent variation in disturbed soil was obtained as a depending on rake angles and the mean values of area did not differ by more than 8% for the three rake angles.

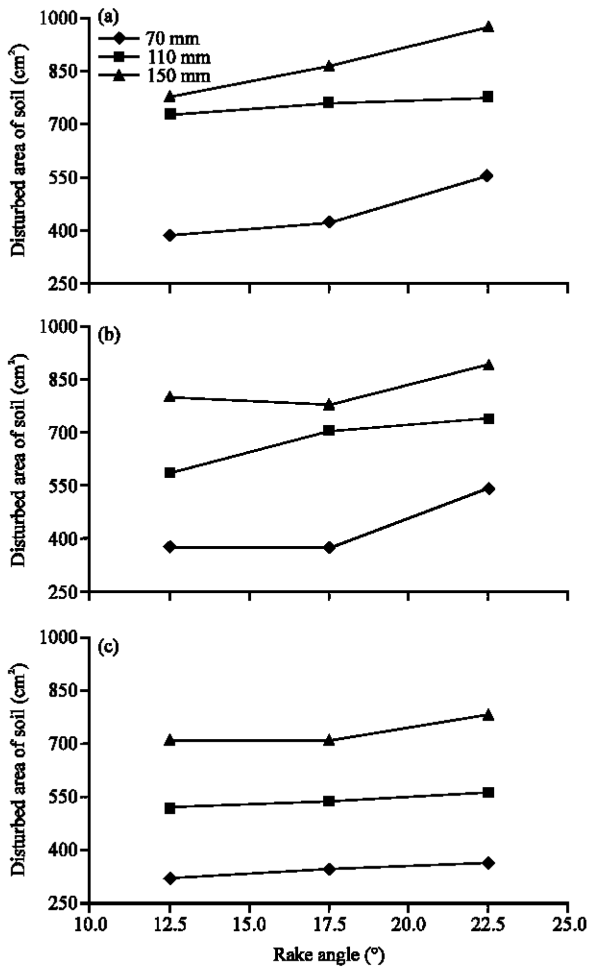

Fig. 4: The effect of rake angle on disturbed area of soil, (a) V: 2.08 m sec^{-1}, (b) V: 1.55 m sec^{-1} and (c) V: 1.08 m sec^{-1}

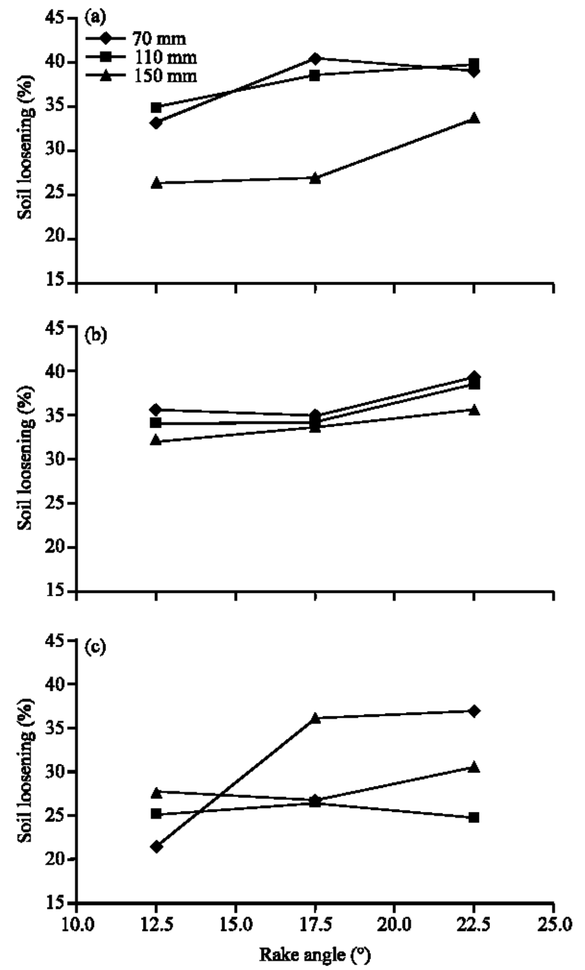

Fig. 5: The effect of rake angle on soil loosening, (a) V: 2.08 m sec^{-1}, (b) V: 1.55 m sec^{-1} and (c) V: 1.08 m sec^{-1}

Approximately, double the working depth resulted in an increase in disturbed area of 97%. Test results confirmed that the variation in disturbed area for forward velocity was greater than the disturbed area caused by rake angle. The effects of treatments on disturbed soil area were significant ($p<0.01$). The greatest disturbed area occurred at rake angle 22.5°, forward velocity 2.08 m sec^{-1} and depth 150 mm.

Soil loosening: The soil loosening increased with increasing rake angle and forward velocity but decreased with increased working depth (Fig. 5). The effect on soil loosening of rake angle and different working conditions were significant ($p<0.01$). The soil loosening varied from 21.07 to 40.45%. The relative change in soil density was generally the smallest at a rake angle of 12.5° and higher at 17.5° and 22.5°. Approximately, an increase of 80% in rake angle caused a 6% increase of the soil loosening.

The degree of loosening was usually larger for higher forward velocity. The percent of soil loosening tended to be higher at smaller working depths, the maximum average loosening being at a depth of 70 mm.

Draft efficiency: Defining draft efficiency as the initial area of soil cut by the draft force, the calculated average values of this quantity are shown in Fig. 6, for each combination of factors. Draft efficiency varied from 3.70 to 9.03 cm^2 daN^{-1}. Although the soil area disturbed did not change appreciably with tool rake angle, the draft increased markedly and this caused a significant decrease of soil cutting efficiency with increasing angle. Efficiency was not affected meaningfully by working depth and forward velocity. As shown by McKeys and Maswaure (1997), it was found that the soil cutting efficiency decreased with increasing rake angle.

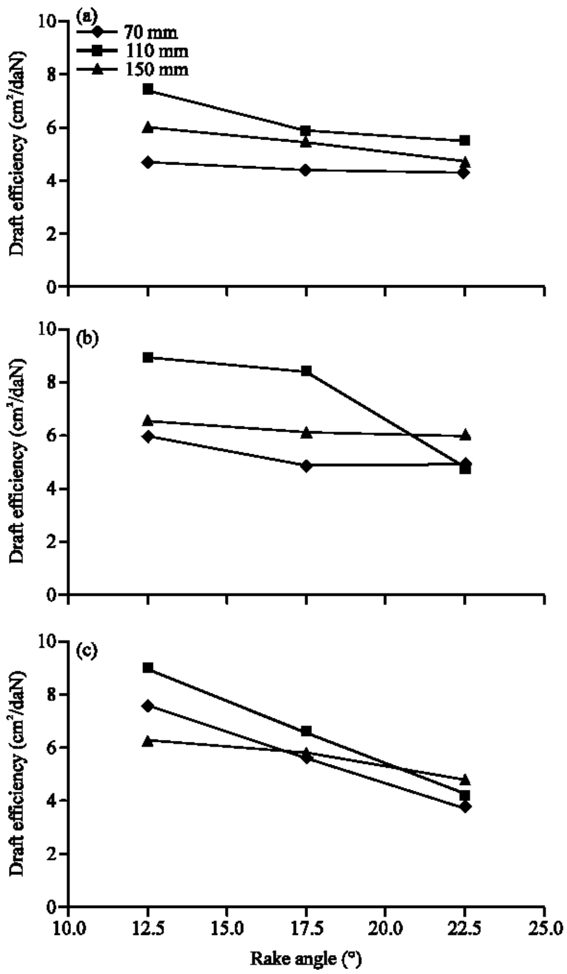

Fig. 6: The effect of rake angle on draft efficiency, (a) V: 2.08 m sec^{-1}, (b) V: 1.55 m sec^{-1} and (c) V: 1.08 m sec^{-1}

CONCLUSION

The following conclusions can be drawn from the soil bin experiments designed to study the interrelationships between rake angle, forward velocity and working depth and the resulting draft force, disturbed area, draft efficiency and soil loosening:

- The draft force was increased with increasing rake angle, forward velocity and working depth. The draft force in different trials varied from 42 to 20.2 daN
- The soil loosening increased with rake angle and forward velocity but loosening decreased with increased working depth. The soil loosening varied from 21.07 to 40.45%
- The disturbed area of soil was larger when tool rake angle, forward velocity and working depth were increased. The greatest disturbed area occurred at rake angle of 22.5°, forward velocity of 2.08 m sec^{-1} and depth of 150 mm
- Tool rake angle was the major contributory factor on draft efficiency as compared to forward velocity and working depth

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