Effects of tilt angle of disk plough on some soil physical properties, work rate and wheel slippage under light clay soil

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Abstract: Standard Disk Plough (SDP) is the integral element of traditional farming system in Middle and Northern Sudan. In SDP, the tilt angle between the planes of the cutting edge of the disk which is inclined to a vertical line may be altered according to the field conditions. Tractor drivers usually use an angle close to maximum in order to decrease the tillage depth, consequently decreasing power requirements, without considering the tillage quality and the impact on the soil properties. This experiment was conducted at the College of Agricultural Studies farm of Sudan University of Science and Technology to study the effects of three tilt angles (15°, 20° and 25°) on soil bulk density, mean weight diameter, wheel slippage, work rate (or effective field capacity) and soil volume disturbed using mounted disk plough. The nature of soil on the farm found to be light clay. The theoretical forward speed was maintained at 6 km/h. The results showed that increasing tilt angle of the plough significantly (p<0.05) increased the bulk density, mean weight diameter and field capacity while significantly decreasing the tractor wheel slippage and soil volume disturbance.

Keywords: disk plough, tilt angle, wheel slippage, effective field capacity, soil volume disturbance, mean weight diameter
DOI: 10.3965/j.issn.1934-6344.2011.02.029-035

Citation: Osman Abdalla N, Li Xia, Zhang Dongxing. Effects of tilt angle of disk plough on some soil physical properties, work rate and wheel slippage under light clay soil. Int J Agric & Biol Eng, 2011; 4(2): 29－35.

1 Introduction

In most traditional farming system of Middle and Northern Sudan, Standard Disk Ploughs (SDP) are very popular among farmers. SDP is used as a primary tillage implement in the ordinary course of land preparation for most of the summer, winter and fodder crops; it can be used for primary tillage of the field[1] and most suitable for soils such as hard, dry and sticky, where moldboard plough will not scour work[2]. The disk blades are set at an angle, known as disk angle from the forward line of travel and also at a tilt angle from the vertical; the disk angles vary from 42° to 45° whereas tilt angles vary from 15° to 25°[3].

In SDP, the tilt angle between the planes of the cutting edge of the disk which inclined to a vertical line may be altered according to the field conditions. In Sudan, tractor drivers usually use an angle close to maximum for decreasing the tillage depth, consequently decreasing power requirements, without regard to the tillage quality and the impact that occurs on the soil properties. If an acceptable result in terms of power requirements could be attained at a maximum tilt angle, then what advantage could be taken in terms of soil bulk density, mean weight diameter (MWD), rear wheel slippage, effective field capacity and disturbed soil volume.

Disk ploughs, which are primarily suitable for the tillage of virgin, stony and wet soils, cut through crop residues and roll over the roots. Blades on disk ploughs are concave, usually representing sections of hollow

Received date: 2011-03-30 **Accepted date:** 2011-05-21
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spheres. The action of a concave disk blade is such that the soil is lifted, pulverized, partially inverted, and displaced to one side[4].

There are many factors that control the performance of disk plough. These factors can be divided into three sections: soil, plough and operation. Soil variables include: soil moisture content (M.C.), organic matter, soil bulk density and structure. Plough variables include: plough weight, disk angle and tilt angle, radius of curvature and disk diameter. Operation variables include: forward speed, width and ploughing depth. Panagrahi et al.[5] determined the effect of tilt angle and soil M.C. on the depth of penetration of a disk plough in varying soil conditions. The experiment was conducted on three types of soils with five different moisture levels for four different tilt angles of the disk plough. The depth of penetration decreased with the decrease in soil M.C. and increased with the decrease in tilt angle.

Sheruddin et al.[6] tested a three – disk mounted disk plough in silt clay loam soil with 17% moisture content. Fuel consumption increased as disk and tilt angles were increased. The field capacity at disk angle 45° and tilt angle 20° was 57.28% greater than with 42°, 16° settings and 11.72% greater than with 43°, 18° settings. In order to plough the maximum area in the minimum time a 45° disk angle is therefore recommended. Hann and Giessibl[7] investigated the effects of varying the speed ratio (from -3 to 6) on the performance of a driven disk for a range of disk angle (20°, 35°, 50° and 65°) and tilt angle (-15°, 0°, 15° and 30°) settings, they found that, increasing disk angle combined with decreasing or negative tilt angles improved soil inversion and pulverization, and driving a disk in either direction improved soil crumbling and mixing characteristics.

Manian et al.[8] studied the influence of operating and disk parameters on performance of disk tools. Studies were conducted in a soil bin containing black clay loam and sand to assess the draught, their results indicated that the 16° tilt angle resulted in lower draught and vertical reaction components (better penetration) as compared to 30° and 24°. Abu – Hamdeh and Reeder[4] observed that, an increasing the tilt angle of the plough increased the draft and vertical forces and decreased the side force.

Adequate utility of soil physical properties is an important management practice for increasing agricultural food production. The main aspect of soil physics for plant productivity is to preserve suitable proportions between solid, liquid and gaseous phases[9]. Buschiazzo et al.[10] determined that manipulation in soil physical properties as a result of soil tillage practices could influence the yield level of grown crops. Aggregate size, moisture content, penetration resistance, and bulk density are among important soil physical properties.

The objective of this study was to evaluate the performance of a medium size standard disk plough (SDP) such as wheel slippage and work rate (or effective field capacity) under three different tilt angle conditions. The different soil physical properties such as soil bulk density, mean weight diameter and soil volume disturbed, were observed under changing standard disk plough tilt angles in light clay.

2 Materials and methods

2.1 Experimental site

The experiment was conducted at the College of Agricultural Studies farm of Sudan University of Science and Technology-Khartoum, North-Sudan. The experiments were conducted during the February and March of 2010. Soil samples were collected at the depth of 0-40 cm to determine soil texture. Soil texture was found to be light clay soil. The soil properties of the 0-40 cm of the experimental site are shown in Table 1. The experimental site prior to this study had been under disk plough in monoculture with animal fodder crops for a long time.

Table 1 Some soil properties of the experimental site

Depth /cm	Bulk density /g · cm^{-3}	Moisture Content/%	Particle Size Distribution/%			Textural class
			Clay	Silt	Sandy	
0–20	1.77	11.52	31	57.1	11.9	Silt clay
26–40	1.54	15.2	57.1	21.4	21.4	Clay

2.2 Experimental design and treatment applications

An experimental plot consisting of three treatments and four replicates was laid out in randomized complete block design (RCBD). The treatments consisted of

3 levels of disk plough tilt angle (1st angle was 15°, the 2nd angle was 20° and the 3rd angle was 25°).

The size of the tillage plots was 60 m×15 m. The plots were separated by 1 m wide buffer strips and there was 3 m gap between 2 plots for the tractor. Average theoretical operating speeds recorded for each tilt angles were 6 km/h, this working speeds was commonly used by farmers and represent actual working conditions and it was achieved by adjusted the engine speed of the tractor at 1 800 r/min by using a hand accelerator lever to maintain steady engine r/min on the dashboard, during field operation tractor was operated with the implement raised up for 100 m and the time was recorded by stopwatch this method followed 10 times and finally the tractor average forward speed was found 6 km/h. Actual travel speed of the tractor for each tilt angles were measured by the same way mentioned above with the implements dropped to down and the tractor traveled the same distance (100 m). Depth for each tilt angles were measured after completing the tillage as the vertical distance from the top of the undisturbed soil surface to the implements deepest penetration. The experiment implement is a medium size standard disk plough. The specifications of the implement are presented in Table 2.

Table 2 Disk plough specification

Parameter	Volume
Type of plough	Fully mounted
Model	Super-AF (BRASIL)
Number of disks	3
Disk Diameter	62 cm
Width of cut	90 cm

Standard disk plough was pulled by Massy Ferguson (MF) 390 tractor. Soil samples from each plot before and after soil tillage were collected for determining soil properties for this study.

2.3 Measurements

2.3.1 Bulk density

Five undisturbed soil samples per four replicates treatments were randomly collected from the upper (0–10 cm) layer of the soil for laboratory determination, using 50 mm × 54 mm cylindrical cores then it was dried at 105℃ for 24 hours after the tillage. The samples were collected a day after the treatments were applied and at weekly intervals thereafter until the sixth weeks. Soil bulk density was calculated by using the following Equation:

$$BD = \frac{W_{dry}}{V}$$

Where, BD = dry bulk density, g/cm^3; W_{dry} = weight of the dried soil sample, g; V = total volume of the soil sample, cm^3.

2.3.2 Mean Weight Diameter (MWD)

To determine the aggregate size distribution, soil samples were randomly taken from the tilled plots using a spade at the 0-10 cm depth soon after the tillage. The moist soil samples were allowed to air dry at a room temperature for 3 months. After the primary tillage, the air dried soil samples were sieved using a set of sieves (mesh openings of 70, 63, 32, 16, 8, 4, and 2 mm) with a shaking time of 30 s[11]. Aggregate size distribution was determined based on the weight of soil in each class with respect to the total soil sample weight. The clod mean weight diameter (MWD) calculated by the following equation was used as an index of aggregate size[12]:

$$MWD = \sum_{i=1}^{n} \frac{Wi}{W} Di$$

Where, W_i = the weight of soil on each special sieve, kg; W = the total weight of experimented soil, kg; D_i= net diameter of each sieve, cm.

2.3.3 Rear wheel slippage (%)

The tractor rear wheel slippage (S) was calculated as a percentage of loss of forward speed as in the following equation[13]:

$$S(\%) = \left(1 - \frac{V_a}{V_t}\right) \times 100$$

The actual travel speed (V_a) for tillage was measured using stopwatch to record the time taken by the tractor to travel specific distance (100 m). Theoretical travel speed (V_t) of the tractor was measured by the same way mentioned above with the implements raised up and the tractor traveled the same distance (100 m).

2.3.4 Effective field capacity (EFC)

The time lost in every event such as turning, adjustment and change of gear was recorded and time lost for real work was used. The field capacity was calculated by using the equation given below[14].

$$EFC = \frac{A}{T_p + T_t}$$

Where, EFC = effective field capacity, ha/h; A = Area tilled, ha; Tp = productive time, h; Tt = non- productive time, h.

2.3.5 Soil Volume Disturbance (SVD)

The total soil volume disturbed was calculated in cubic meters per hour by multiplying the effective field capacity with the depth of cut as below. It was assumed that the implement disturbed the soil up to its recorded depth and no undisturbed patch of land was left.

$$V=10\,000\,C\,D$$

Where, V = Soil volume disturbed, m^3/h; C = Field capacity, ha/h; D = Depth of cut, m.

2.4 Statistical analysis

tatistical analysis was accomplished by StatView. Analysis of variance (ANOVA) was used to evaluate the significance of each treatment on all parameter under this study in a randomized complete block design with 4 replications. Comparison of means was performed with Duncan's multiple range tests.

3 Results and discussion

In order to determine the effect of tilt angles on soil bulk density, mean weight diameter, wheel slippage, effective field capacity and soil volume disturbed the variance analysis are given in Table 3.

Table 3 Statistical description of variation for all observed parameters affected by different tilt angles

Observed Parameters	M.S	P. value	LSD	C.V/%
Bulk density/g · cm^{-3}	0.007	0.0021	0.032	3.2
MWD/mm	5.421	0.0029	0.946	4.6
Wheel slippage./%	8.320	0.0001	0.483	11.1
Field capacity/ha · h^{-1}	1.651	0.0006	0.004	1.5
SVD/m^3 · h^{-1}	2 973.6	0.0001	2.851	3.7

3.1 Effects of different tilt angles on bulk density

In order to determine the effect of tilt angles on soil bulk density the variance analysis are given in Table 3. Bulk density reflects the soil condition disturbed. Figure 1 shows the changing pattern in mean values of bulk density of the soils at different weeks after the tillage operation for the three tilt angle under consideration. An increasing trend was observed in bulk density over time for all treatments as the soil gradually got compacted under the influence of particle resettlement.

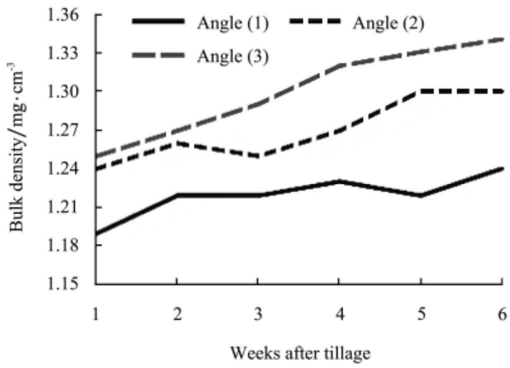

Figure 1 Mean bulk density of surface (0–10 cm) soil, under different tilt angles over time

A statistically significant difference (P<0.05) was observed in bulk density between angle (1) and other two angles (Table 2).

Figure 2 indicates the effect of different tilt angles on mean bulk density (when averaged over all the weeks) at experiment site. It is clear that the increase of tilt angle from 15° to 25° tends to increase the soil bulk density. In general, the bulk density in angle (3) was found to be higher than angle (1) by 6.55%.

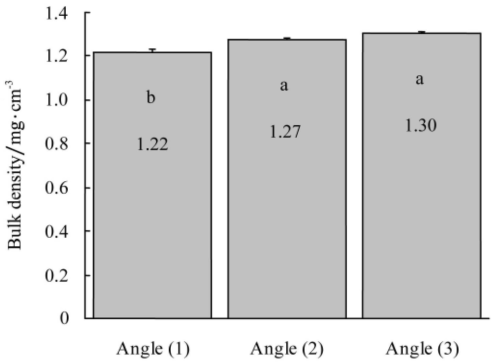

Figure 2 Mean soil bulk density affected by different tilt angles. (mean followed by the different letter differ significantly according to Duncan's test)

As reported by others, Soil bulk density, penetration resistance (PR), and water movement in the soil, all indices of soil compactness and porosity, depend on depth and method of tillage[15-17]. The effect of tillage depth and method on these soil physical properties were found variability in crop growth, crop development, yield, and quality[15-17]. Infiltration rate and crop yield increased with increasing the ploughing depth[18]. Abu-Hamdeh and Reeder[4] observed that a decrease in tilt angle leads to increase in implement penetration. Therefore, and based on above, the decrease that occurred in tilt angles led to increase soil inverts and looseness. Thus, may reduce the soil bulk density.

3.2 Effects of different tilt angles on mean weight diameter (MWD)

Over the course of the study, tilt angles significantly different (P<0.05) affect mean weight diameter (Table 3). As shown in Figure 3, an increase in the tilt angle from 15° to 20° led to increase the MWD from 23.04 mm to 24.03 mm and an increase in the tilt angle from 20° to 25° also led to a correspond increase in the MWD from 24.03 to 25.36 mm. The MWD in angle (3) was found to be higher than angle (1) by 10.06%. This may be due to a decrease in the tilt angle which leads to an increase in soil inversion and thus increase soil fragmentation and crumbling. Abu-Hamdeh and Reeder[4] observed that a decrease in tilt angle leads to increase in implement penetration. Ali[19] reported that a reduction of tilt angles resulted in increase soil inversion.

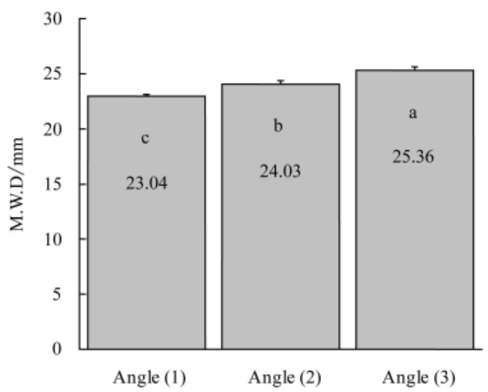

Figure 3 Mean of MWD (mm) affected by different tilt angles. (mean followed by the different letter differ significantly according to Duncan's test)

3.3 Effects of different tilt angles on wheel slippage

The statistical analysis in Table 3 shows that there are significant differences (P>0.05) in wheel slippage between various tilt angles. Figure 4 shows the effects of tilt angles on wheel slippage. It could be observed that, when the tilt angle was decreased from 25° to 20° leaded to increase in wheel slippage from 10.1% to 10.9%. In contrast reduction of tilt angle from 20° to 15° also led to increase in slippage from 10.9% to 12.9%. In general the slippage in angle (1) was found to be higher than angle (3) by 27.7%. This may be attributed to that the decrease of the tilt angle has to increase the implement depth and thus increase wheel slippage. The percentage of wheel slippage increased with increasing the amount of implement draft[20,21]. A reduction of ploughing depth reduces the slippage[22].

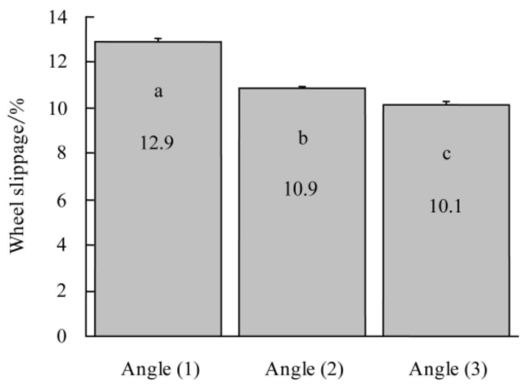

Figure 4 Mean wheel slippage affected by different tilt angles. (mean followed by the different letter differ significantly according to Duncan's test)

3.4 Effects of different tilt angles on effective field capacity and soil volume disturbance

The differences in field capacity as well as volume disturbed between different tilt angle were statistically significant (P<0.05) (Table 3). Effective field capacity and volume disturbed created by operating various tilt angles were worked out, and such results are presented in Figures 5 and 6. An area of 0.09 hectare was tilled. The results indicated the productive time of angle (1) was 13.12 minutes and non productive time was 1.016 minutes and ploughing depth was 17.1 cm, producing field capacity of 0.382 ha/h and soil volume disturbance of 653.22 m^3/h. Productive time, non productive time and ploughing depth in angle (2) were 13.013 minutes, 1.012 minutes and 16.44 cm respectively, producing field capacity of 0.385 ha/h and soil volume disturbance of 633.02 m^3/h. While productive time of angle (3) was 12.65 minutes, non productive time was 1.01 minutes with ploughing depth of 14.90 cm, producing field capacity and soil volume disturbance of 0.394 ha/h and

598.88 m^3/h respectively.

The results indicated that the highest effective field capacity was recorded in angle (3) while, angle (1) recorded the highest value of soil volume disturbance. This may be due to with an increase in the depth and slippage of an implement leads to decrease an implement speed thus decreased effective field capacity.

A reduction of ploughing depth reduces the slippage[22]. Aziz[23] reported that, a reduction in wheel slippage resulted in increase implements speed.

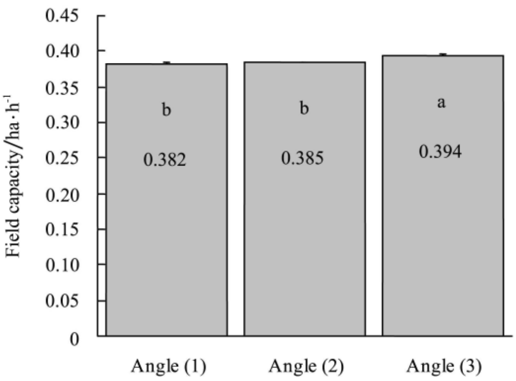

Figure 5 Mean effective field capacity affected by different tilt angles. (mean followed by the different letter differ significantly according to Duncan's test)

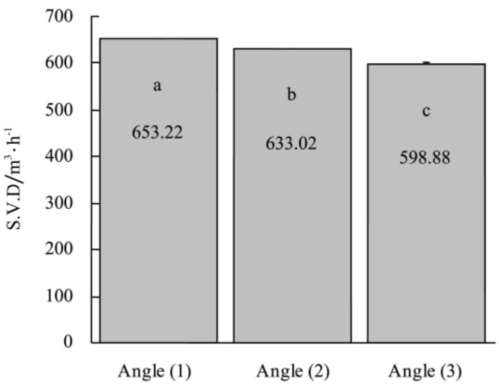

Figure 6 Mean SVD affected by different tilt angles. (mean followed by the different letter differ significantly according to Duncan's test)

4 Conclusions

1) Bulk density, mean weight diameter, wheel slippage, effective field capacity and soil volume disturbance at different tilt angles of a light clay soil were measured and evaluated.

2) Bulk density significantly affected by different tilt angles, which increased with increasing tilt angle, also it increased with increasing length of time after tillage

3) Mean weight diameter was significantly affected by tilt angles. The lowest MWD was recorded in angle (1), while the highest MWD in angle (3).

4) There were significant differences in wheel slippage among the tilt angles. Wheel slippage under angle (1) was greater than the others angles.

5) The differences in field capacity as well as volume disturbed between different tilt angles were statistically significant. The highest field capacity was recorded in angle (3), while angle (1) recorded the highest value of soil volume disturbance.

Acknowledgments

The authors would like to thank Agric. Engineering Department Staff in Sudan University. The assistance provided by Engineers Nsreen Mohamed and Ali Mohamed during the field work and data analysis is highly appreciated. Thanks for the financial support from The National Maize Industry Technology R&D Center; Mechanized corn(CARS-02) production system optimization technology and equipment research demonstration projects (200903059).

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