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The Response of Mounted Disc Plow Operating Variables on Machine and Tractor Performance in Light Clay Soil

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Abstract

The experiment was conducted at the College of Agricultural Studies Farm of Sudan University of Science and Technology-Khartoum North in 2019. The nature of the Soil on the farm was found to be light clay soil. The experiment aimed to study the effect of two disc angles (40°and 45°) and two tilt angles ($15^0$and 25°) on effective field capacity, field efficiency, tractor wheel slip and fuel consumption rate using a mounted disk plow. The results showed that increasing the disc and tilt angles of the plow significantly ($p<0.05$) increased plow field capacity and field efficiency. Increasing disc angle of the plow significantly increased tractor wheel slippage, while the minimum values of the disc and tilt angles gave a low rear wheel slippage (13.1%). Increasing tilt angle and disc angle of the plow led to increase in fuel consumption rate. Moreover, results showed that 5.6 L/fed was the optimal consumption rate, which from the combined effect of 40° disc angle and 15° tilt angle.

Keywords*:* Wheel slippage, Disc plow, Disk angle, Tilt angle, Field efficiency.

Introduction

Farm machinery is an important element for agricultural development and crop production in many developed countries. . Farm machinery offers several potential improvements for farming system such as increased land and labor productivity, reduction of risk, increase of food quality and safe of time. Crop production requires a number of operations like seed bed preparation, seeding, fertilizing, spraying, dusting, irrigation and harvesting. The first operation in production of any crop is the tillage operation.

Tillage is a mechanical manipulation of soil to provide favorable conditions for crop production. Soil tillage consists of breaking the compact surface of earth to a certain depth and to loosen the soil mass, so as to enable the roots of the crops to penetrate and spread into the soil. Tillage may be called the practice of modifying the state of soil to provide favorable conditions for plant growth. Tillage operation is the most labour

consuming and difficult operation compared to all subsequent operations in the field. The main objective of the machinery is to reduce number of labor, the difficulties of farm operations and maximize production. Agricultural mechanization has been receiving a considerable interest in recent years due to increasing demand for food due to the expansion of world population (Abdalla *et al.,* 2014).

Soil tillage may be defined as the mechanical manipulation of the soil aimed at improving soil conditions for crop production. It represents the most costly single item in the budget of an arable farmer. Tillage provides good weed control with low herbicide cost; allows the control of disease and insects by destroying them through burying of crop residues. Proper selection of tillage implement that suits available power, crop type and soil condition is important to reduce energy required. Disc plow is widely used by farmers In irrigated farming system of Sudan as a primary tillage implement of land preparation for most of the cultivated field crops. Performance data for disc plow is essential in order to optimize its performance and reduce the cost of tillage operation. Field efficiency, Theoretical and effective field capacity mentioned by Abdalla (2014) are the main performance parameters; therefore, it is important to select the suitable machine or machines to carry out the specific operation with minimum cost of energy and in the required time under suitable field condition. The disk plow was developed as an alternative to be used in soil conditions where the moldboard plow would not work well such as heavy, dry and sticky soils (Mohamed, *et al 2018).* The disc blades are set at an angle, known as disc angle inclined to the forward line of travel and also at a tilt angle from the vertical; the disc angles vary from 42° to 45° whereas tilt angles vary from 15° to 25° In mounted disc plough, 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 (Fig. 1). 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°. Kepener, *et al*., (1982) and Al-Hashimy (2003) concluded that the increase of tilt angle decreased discs penetration in the soil which led to an increase in the effective field capacity due to the increase of the actual cutting width. Bukhari, *et al*. 1992, Osman and Dongxing (2011) found that as disc and tilt angles increased, the field capacity and fuel consumption rate increased. 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 Osman and Dongxing (2011)

Fig.(1): Disc and Tilt angles of the plow

There are many factors that control the performance of disc plow. These factors can be divided into three sections: soil, plow and operation. Soil variables include: soil moisture content (M.C.), organic matter, soil bulk density and structure. Plow variables include: plow weight, disc angle and tilt angle, radius of curvature and disk diameter. Operation variables include: forward speed, width and plowing depth. Many studies have been conducted to test the performance of disc plows in numerous different ways under specific operating conditions. Panagrahi *et al.,* determined the effect of tilt angle and soil M.C. on the depth of penetration of a disc plow 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 plow. The depth of penetration decreased with the decrease in soil M.C. and increased with the decrease in tilt angle. Sheruddin *et al.,* (1992) tested a three – disc mounted disc plow in silt clay loam soil with 17% moisture content. Fuel consumption increased as disc and tilt angles were increased. The field capacity at disc 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° disc angle is therefore recommended. Hann and Giessibl(1998) investigated the effects of varying the speed ratio (from -3 to 6) on the performance of a driven disc for a range of disc angle (20°, 35°, 50° and 65°) and tilt angle (-15°, 0°, 15° and 30°) settings, they found that, increasing disc angle combined with decreasing or negative tilt angles improved soil inversion and pulverization, and driving a disc in either direction improved soil crumbling and mixing characteristics. Manian *et al.,* (2000) studied the influence of operating and disc parameters on performance of disc 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 (2003) 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. Buschiazzo *et al.,* (1998) 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. . An experiment was conducted at the Agricultural Research Station, Mutah University in 2007 to study the effect of plowing speed, disc and tilt angles on tractor wheel slippage and on plowing depth (Manian and Kathirvel 2000) .The result showed that increasing the plowing speed significantly increased tractor wheel slippage , the minimum value found was 3.9 % at 4k/hr when disc angle was 35^0 . (Glinski and Lipiec 1990)tested a three disc mounted plow in silt clay loam soil with 17% moisture content .They concluded that fuel consumption and field capacity values increased as disc and tilt angles were increased . Mamkagh (2009) studied the effect of three plowing speeds, three disc angles and three tilt angles on the tractor wheel slippage and plowing depth using amounted disc plow. The results showed that increasing the plowing speed significantly, increased tractor wheel

slippage and plowing depth, also increasing tilt and disc angles of the plow significantly increased the tractor wheel slippage. An experiment was conducted by Abdalla *et al.,* (2014) at Farm of the Faculty of Agric. University of Khartoum to study the effect of two disc angles (43.and 45) and three disc angles (15, 20 and 25) on tractor and plough field performance.

They reported that effective field capacity was increased by 16% with the decrease of disc angle while , The decrease of tilt angle improved penetration of discs into the soil , which consequently led to an increase of both rear wheel slippage and fuel consumption rate . It was concluded from the results obtained by Taiwa *et al.,* (2015) that the wheel slippage of the tractor for first and second plowing operations when mounted with a 2-bottom disc plough were 10.31 and 12.13 % respectively while they were 9.92 and 11.93 % respectively when mounted with a 3-bottom disc plough. The results from a research work conducted by Osman and Dongxing (2011) showed that increasing tilt angle of the plough significantly (p<0.05) increased the field capacity while significantly decreasing the tractor wheel slippage and soil volume disturbance.

An experiment was conducted at the Agricultural Research Station, Mu'tah University by Mamkagh 2009, to study the effect of three plowing speeds (4, 7 and 10km/h), three disk angles (35°, 45° and 55°) and three tilt angles (15°, 20° and 25°) on tractor wheel slip and plowing depth using mounted disk plow. The results showed that increasing the plowing speed significantly (p<0.05) increased tractor wheel slip. Increasing disk angle of the plow significantly increased tractor wheel slip, Increasing tilt angle of the plow significantly increased the tractor wheel slip and significantly decreased the plowing depth. Results showed that 3.9% was the optimal wheel slippage, which was obtained from the combined effect of 4 km/h plowing speed, 35° disk angle and 15° tilt angle.

The objective of this study was to evaluate the performance of a medium size standard mounted disc plow such as rear wheel slippage , fuel consumption and effective field capacity under two different disc angles and two tilt angles of the disc plow.

Materials and Methods

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 October and November of 2018. 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 experiment site

Depth (cm)	Bulk Density (g/cm3)	Moist content %	Particle Size Distribution %			
			Clay	Silt	Sandy	Texural class
0 - 20	1.77	11.5	31	57.1	11.9	Silt clay
26 - 40	1.5	15	57.1	21.4	21. 4	Clay

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°, the2nd 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 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 1800 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 stop watch 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.

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.

Table2: Disc plow specifications

Parameter	***Specifications***
(Hitching)	Fully mounted
Model	Super- AF (Brazil)
Number of discs	3
Disc diameter	62cm
Width of cut	90cm

Measurements:

- **Fuel consumption measurement**:

The fuel tank of MF-285 tractor was filled up to its top level before field testing. After tillage operation, the tractor engine was stopped and the fuel tank was re filled up to the same level with a graduated cylinder ,the amount of fuel used for refilling the tank was recorded and the time taken to finish specific plot was also recorded, and The fuel consumption rate in (l/fed) was calculated.

$$TF = \frac{F}{A \times 1000} \quad \ldots\ldots\ldots\ldots \quad (1)$$

Where: TF = Total fuel consumed (lit/ha)
F = Fuel consumed (mlit
A = Area covered (ha)

- **Measurement of tractor rear wheel slippage:**

The measurement of wheel slippage was done for rear wheel of MF 285tractor. At first the distance traveled by plow for 10 revolutions of the tractor rear wheel was recorded at without load. Then after three observations were taken for the same number of revolutions when operated with load. The average of these observations was calculated. The percentage wheel slippage of two plows was then calculated as follows:-

$$\text{Slippage\%} = \frac{L1 - L2}{L1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where**:** L_1 = actual distance traveled (without loaded) (m**)**

L_2 = theoretical distance traveled (with load) (m**)**

c) Effective field capacity and field efficiency:

The time was recorded and the ploughing width was determined using the steel tape, then the effective field capacities and field efficiencies were calculated.

$$\text{E ffective field capacity} \frac{(EFC)fed}{hrs} \qquad \frac{\text{Plot area)}}{\text{Total time require to cover the plot (hr)}} \ldots\ldots\ldots (3)$$

Plow field efficiency (%): = Effective field capacity (fed/hr) × 100%.....(4)
Theoretical capacity(fed/hr)

Statistical analysis

Statistical analysis was used by Statistics – 8 Version. T-test to evaluate the significance of each treatment on all parameters under this study in a randomized complete block design with replications.

Results and Discussion:

1. Effect of Disc and Tilt Angles on plow Effective Field Capacity:-

Table (3) shows the effective field capacity (fed/hr) of the disc plow at different tilt and disc angles. It can be observed from table(3) that the disc angle 45 with tilt angle 25 recorded high effective field capacity (0.95 fed/h) as compared to the disc angle 40 with tilt angle 15, which recorded the lowest effective field capacity (0.91 fed/h). This result agrees with the results of Glinski and Lipiec(1990), Osman and Dongxing (2011) who reported that the increase of tilt angle led to decrease discs penetration in the soil which led to an increase in the effective field capacity due to the increase of the actual cutting width . The statistical analysis T test (table 4a, 4b) showed that there are no significant differences in effective field capacity between various disc and tilt angles.

Table (3): Effective field capacity (EFC fed/hr)at different angles of the disc plow

Disc angle	Tilt angle	EFC (fed/hr)
40^o	15^o	0.91
40^0	25^o	0.93
45^0	15^o	0.92
45^0	25^o	0.95

Table (4a): Paired T Test for Angle1 - Angle2

Mean	Std Error	Mean - H0	Lower 95% CI	Upper 95% CI	T	DF	P
-9.00E-03	6.66E-03	9.00E-03	-0.0376	0.0196	-1.35	2	2

*Disc1: disc angle40^o and tilt angle15^o - Disc2: disc angle45^o and tilt angle15^o

Table (4b): Paired T Test for disc3 - disc4

Mean	Std Error	Mean - H0	Lower 95% C	Upper 95% CI	T	DF	P
-0.0233	8.82E-03	0.0233	-0.0613	0.0146	-2.65	2	.1181

*Disc3: disc angle40^o and tilt angle25^o - Disc4: disc angle45^o and tilt angle25^o

2- **Effect of Disc and Tilt Angles on plow Field Efficiency:-**

Table (5) shows the values of the field efficiency of the disc plow operating at different disc and tilt angles. It could be recorded from the table that high values of field efficiency were obtained at maximum tilt angle (25), where low percentage of field efficiency was recorded at minimum degrees of tilt and disc angles . Statistical analysis (table 6) showed that there are significant differences in plow field efficiency between various disc and tilt angles of the disc plow.

Table (5) : Field efficiency (%) at different angles of the disc plow

Disc angle	Tilt angle	Field Efficiency %
40^o	15^o	71
40^0	25^o	73
45^0	15^o	72
45^0	25^o	74

Table (6): Paired T Test for disc – tilt (field efficiency)

Mean	Std Error	Mean - H0	Lower 95% CI	Upper 95% CI	T	DF	P
22.500	3.2275	22.500	12.229	32.771	6.97	3	0.0061

3- **Effect of tilt and disc angles of a disc plow on tractor rear wheel slippage:**

The means percentage of the tractor rear wheel slippage for the two disc angles and the two tilt angles are presented in table (7). From the table it could be observed that as disc angles and tilt angles increase the slippage percentage also increases. The 45 disc angle gave a high value of rear wheel slippage (22.5 %) where the tilt angle is 25, and it was 18.3% where the tilt angle is 15. This may be attributed to that, the decrease of the tilt angle has to increase depth and thus increase wheel slippage. The value of the disc angle 40 gave a minimum slippage percentage (13.1%) where the tilt angle was 15. These results agree with Mamkagh (2009) who reported that increasing both tilt and disc angles of the plough significantly increased the tractor wheel slippage.

Table (7): Tractor rear wheel slippage at different angles of the disc plow

Disc angle	Tilt angle	Rear wheel slippage(%)
40^o	15^o	13.1
40^0	25^o	16.7
45^0	15^o	18.3
45^0	25^o	22.5

Table (8): Paired T Test for disc – tilt angles (Slippage %)

Mean	Std Error	Mean - H0	Lower 95% CI	Upper 95% CI	T	DF	P
22.500	3.2275	22.500	12.229	32.771	6.97	3	0.0061

Statistical analysis (table 6) showed that there are significant differences in tractor rear wheel slippage between various disc and tilt angles of the disc plow.

4- **Effect of disc and tilt Angles on tractor fuel consumption:-**

The results of fuel consumption rate (L/fed) are shown in table 9. Highest fuel consumption rates 10.3 l/fed , and 8.2l/fed were recorded by the disc angle 45^o with tilt angle 25^o,and 15^o respectively, while disc angle 40^o with tilt angle 15^o gave the lowest rate (5.6 l/fed). These results agree with Abdalla *et al*. (2014), Bukhari, *et al*., (1992) and Osman, and Dongxing (2011) who found that fuel consumption increased as disc and tilt angles were increased.

Table (9): Fuel consumption rate at different angles of the disc plow

Disc angle	Tilt angle	Fuel consumption (L/fed)
40^o	15^o	5.6
40^0	25^o	6.7
45^0	15^o	8.2
45^0	25^o	10.3

Statistical analysis (table10) showed that there are **.**significant differences in tractor fuel consumption rates between various disc and tilt angles of the disc plow.

Table (10): Paired T Test for disc – tilt angles (fuel consumption rate)

Mean	Std Error	Mean - H0	Lower 95% CI	Upper 95% CI	T	DF	P
22.500	3.2275	22.500	12.229	32.771	6.97	3	0.0061

Conclusion:

1) Effective field capacity, tractor rear wheel slippage, and fuel consumption at different tilt and disc angles of a light clay soil were measured and evaluated.

2) The disc angle 45 with tilt angle 25 recorded a high effective field capacity, and there are no significant differences in effective field capacity between various disc and tilt angles.

3) It could be observed that as disc angles and tilt angles increase the slippage percentage also increases.

4) Highest fuel consumption rates were recorded with an increase of disc and tilt angles, while decreasing disc and tilt angles will lead to decrease in fuel consumption rate.

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إستجابة أداء الالة والجرار للمتغيرات التشغيلية للمحراث القرصي في الأراضي الطينية الخفيفة

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المستخلص

أجريت التجربة في مزرعة كلية الدراسات الزراعية بجامعة السودان للعلوم والتكنولوجيا – الخرطوم بحري عام 2019. حيث وجد أن طبيعة التربة في المزرعة هي تربة طينية خفيفة. هدفت التجربة إلى دراسة تأثير استخدام زاويتي قرص (40 درجة و 45 درجة) وزاويتي ميل (15 درجة و 25 درجة) على السعة الحقلية الفعلية والكفاءة الحقلية وانزلاق عجل الجرار ومعدل استهلاك الوقود باستخدام المحراث القرصي المعلق. أوضحت النتائج أنه و مع زيادة زوايا القرص والميل للمحراث أدت إلى زيادة معنوية ($p < 0.05$) في السعة الحقلية الفعلية والكفاءة الحقلية. كذلك أدت زيادة زاوية قرص محراث القرصي إلى زيادة معنوية في انزلاق عجل الجرار بشكل كبير ، بينما أدت القيم الصغري لزوايا القرص والميل إلى قيم انزلاق منخفضة للعجلة الخلفية (13.1٪). أدت زيادة زاويتي الميل و القرص إلى زيادة معنوية في معدل استهلاك الوقود. علاوة على ذلك ، أظهرت النتائج أن أفضل معدل لاستهلاك الوقود والذي قدر ب 5.6 لتر / فدان وجد من خلال التأثير المشترك لزاوية القرص 40 درجة وزاوية الميل 15 درجة.