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Performance of Disc and Chisel Ploughs and their Effects on Some Soil Physical Properties

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Abstract: A study was carried out at the University of Khartoum Demonstration Farm in (2007), to study the performance of two tillage implements: (disc and chisel plough) and their effect on some soil physical properties. The results showed that the higher values of both theoretical and effective field capacities were recorded by chisel plough (1.23 ha/hr and 0.90 ha/hr) as compared to disc plough (0.63 ha/hr and 0.50 ha/hr). The higher field efficiency was recorded by disc plough (79.37%) as compared to the chisel plough (73.4%). The fuel consumed when using the disc plough was (10.60 l/ha) less than that consumed by the chisel (13.47 l/ha). Tractor wheel slippages ware found to be 10.92%. and 14.1%. The result also showed that both ploughs decreased the soil bulk density values from 1.54 g/cm^3 to 1.51 and 1.49 g/cm^3 by disc and chisel plough respectively. Particle density was not affected ($P > 0.05$) by both implements . The soil porosity values were also increased for both implements. The soil moisture content recorded in two depths 0-15 and 15-30 cm were higher for chisel plough (6.53% and 6.9%) as compared to disc plough which recorded 6.3% and 6.5% respectively. The infiltration rate obtained by the disc plough was 22.2 cm/hr while that of chisel plough was (20.1 cm/hr).

Key words: Disc plough; chisel plough; soil physical properties.

INTRODUCTION

Sudan is ranked one of the world greatest potential areas for agricultural production. The total area of the country, before Southern Sudan separation, is about 2.5 million square kilometers (250 million hectares), two third of this land is classified as suitable for agricultural cultivation, livestock, forest and range. The estimated arable land for agricultural production is more than 8.4 million hectares. This is equivalent to about 32% of total arable land in Africa (Kaumbuth, 2000) and more than 46% of the land suitable for agricultural investment in the Arab world (Elsayed, 1999). Out of this potential area only 20% is currently under cultivation.

The cultivated area of the Sudan can be classified into two main sectors, namely the rain fed and the irrigated sectors. Irrigated agriculture has been practiced since 1925 in Gezira project and more than three decade in Rahad and New Halfa. The irrigated sector used to produce 100% of sugar, 95% cotton, 36% dura and 32% of groundnut and most of vegetables and fruits. The rain fed agriculture occupies an area of 10.5 million ha and plays an important role in the national economy. It contributes about 95% of the food security for the country and absorbs about 66% of the labor force (Mohamed and Farah, 1999). The rain fed sector includes, the mechanized rain fed and traditional agriculture, in an area of 7.14 million ha. The major crops produced in this sector are dura, cotton, sunflower and sesame. Rain fed agriculture in Sudan is characterized by low productivity due to many reasons such as variation in rain, low fertility, insect and pest infestation. The traditional agriculture represents about 8.4–10.5 million ha and produces a number of crops such as dura, maize, sesame, watermelon (Mohamed and Farah, 1999).

The determination of the performance of tillage implements and their effect on soil physical properties is of vital importance to alleviate the prevailing land deterioration. The analysis of soil before and after tillage might be a useful tool to determine the optimum tillage requirement. The general objectives of this study are to study the performance of chisel and disc ploughs and their effects on soil physical properties, and develop specific procedures for improvement of the low level productivity of various crops. The specific objectives of the study were:

1- To measure the theoretical, effective field capacities (TFC, EFC) and field efficiencies (FE) of chisel and disc ploughs.
2- To determine Tractor fuel consumption (FC) and wheel slippage as affected by Disc and Chisel plough.
3- To study the effect of using chisel and disc ploughs on some soil physical properties (bulk density, moisture content, particle density, soil porosity and infiltration rate).

MATERIALS AND METHODS

The experimental site

The experiment was carried out at the Demonstration Farm of the Faculty of Agriculture, University of Khartoum, Shambat (longitude 32^{o} 32 E, latitude 15^{o} 40 N). The total area of the experiment was 8400 m^2. The soil of the experimental area was generally clay loam.

Agricultural machinery

A 75 hp, 2 WD Case International tractor of general purpose was used in the experiment as a power source for drafting tillage implements.
Two main primary tillage implements were used in the experiment:

1- A fully mounted, Pandal disc plough, with three bottoms. Disc diameter was 34 inches.

2- A fully mounted, Newholland make, chisel plough with 5 shanks.

Equipments

A measuring tape, 30 m long was used for measuring the dimensions and distances to calculate area of plots and width of implements. Steel pegs were used for marking the travel (or trip) distance during experiment. Stop watch was used for determining the time for calculation of speed of operation of tractor and fuel consumption rate. A piece of chalk was used for marking the distances of plots and sings on the wheels of tractors for measuring slippages. A 1000 ml measuring cylinder was used for refilling the tractor fuel tank, to determine fuel consumption rate during each operation.

A double ring infiltrometer was used. The two concentric cylinders were 23 cm deep and formed of 2 mm rolled steel. The outside and inside diameters were 30 and 20 cm respectively. Hammer and wooden plank were used for driving the cylinder into the ground.

Experimental design and layout

The experiment included 2 treatments (disc and chisel ploughs) which were replicated 3 times. The area of the experiment was divided into six plots (28 m x 50 m). A random distribution of treatments within the plots was carried out. The experiment was arranged in a Randomized Complete Block Design (RCBD).

Measurement of field capacities and efficiencies

Field capacities and efficiency were measured by the following steps:

1. On each plot a distance of 50 m was marked.
2. The tractor started working the plot, and the time in seconds was recorded. This procedure was repeated for each plot.
3. Time for turns per seconds at the end of each distance was recorded.
4. The productive time was determined as follows:
   Productive time (hr) = sum of time required to finish an area of 1400 m^2
5. The time required to finish the plot was computed as follows:
   Total time = time for turns + productive time + other time
6. The theoretical and effective field capacities (TFC, EFC) and field efficiencies (FE) of the plough were then calculated as explained below:

For calculation of theoretical field capacity the following equation as stated by Smith and Wilkes (1977) was used:

$$TFC = \frac{W.S}{10} \quad \text{..} (1)$$

Where:

TFC = theoretical field capacity, ha/h
W = Implement width, m
S = Tractor speed, km/h

When disc and Chisel Ploughs were used respectively

$$EFC = \frac{A}{T \times 10000} \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where:

EFC = effective field capacities, ha/h
A = area of the plot, 1400 m^2
T = time needed to cover plot, hr

$$FE(\%) = \frac{EFC}{TFC} \times 100 \ldots\ldots\ldots\ldots(3.1)$$

Where:

FE (%) = field efficiency
EFC = effective field capacity, ha/h
TFC = theoretical field capacity, ha/h

$$FE(\%) = \frac{Pr}{Tt} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots(3.2).$$

Where:

P_r = Productive time, hr
T_t = Total time in the field, hr

Measurements of fuel consumption

The following steps show the method used for the measurement of fuel consumption:

1- The tractor started working the plot with its full tank capacity.
2- After finishing the plot, the tank was refilled with graduated cylinder.
3- The amount of fuel used to refill the fuel tank was recorded in ml.
4- The time taken to finish the plot was recorded.
5- The fuel consumption rates were calculated in l/hr as follows:

$$F.C. = \frac{R.C.}{T \times 1000} \ldots\ldots\ldots\ldots(4)$$

Where:

F.C. = Fuel consumption, l/hr
R.C. = Reading cylinder, ml
T = Time, hr

Measurement of rear wheel slippage

The rear wheel slippage was determined as follows:

1-A fallow flat area was chosen in the field to represent normal working conditions.

2-The rear wheel of the tractor was marked by a piece of chalk at a position tangent to ground surface.

3-A distance covered by six revolutions of the wheel when the tractor was unloaded was measured.

4-Another distance covered by the same number of revolutions was measured when the tractor was loaded with the implement.

5-The wheel slippage was calculated as follows:

$$Wheel slippage\% = \frac{Unloaded distance - loaded distance}{unloaded distance} \times 100 \ldots\ldots\ldots\ldots (5)$$

6-All the above steps were repeated for the two implements at the same forward speed.

Soil physical properties

Soil analyses were carried out at the Soil Science Laboratory of the Faculty of Agriculture, University of Khartoum. The soil physical properties under the study included: bulk density, moisture content, particle density, soil porosity, hydraulic conductivity and infiltration rate.

Bulk density

The bulk density of the soil was measured using the clod (paraffin wax) method as follows:

From each main plot (tillage treatment), undisturbed soil clods were taken using an auger. The samples were collected from two depths 0-15 and 15-30 cm. These clods were weighed (W_1), coated with paraffin wax whose density is (d) and reweighed (W_2). The coated clod volume (V) was then determined by dipping the clod in water; and its volume was taken to be equal to the displaced water volume. The bare clod volume was calculated by subtracting the wax volume [(W_2- W_1)/d] from the coated clod volume. Thereafter, the bulk density was calculated from the following equation as stated by Makki (2002):

$$B_d = \frac{W_1}{V - [(W_2 - W_1)/d]} \dots\dots\dots\dots\dots\dots\dots\dots(6)$$

Where:

B_d = Bulk density, g/cm^3
W_1= Clod weight, g
W_2= Clod and paraffin wax weight, g
V = Coated clod volume, cm^3
D = paraffin wax density, g/cm^3

Soil porosity

The soil porosity was calculated by using the formula proposed by Makki (2002) as follows:

$$porosity(\%) = 100 \times \left(1 - \frac{B_d}{P_d}\right) \dots\dots\dots\dots\dots\dots\dots\dots(7)$$

Where:
B_d = soil bulk density, g/cm^3
P_d = particle density, g/cm^3

Particle density

Particle density of the soil was determined using the cylinder method as described by Blake (1965). The increase in the volume of water column in a measuring cylinder was found after pouring it into the soil samples, the following formula was used to calculate the particle density:

$$\left(P_d\right)=\frac{M}{V}\text{..}(8)$$

Where:

Pd = particle density, g/cm^3
M = mass of the soil clod, g
V = volume of the soil clod, cm^3

Soil moisture content

From each main plot (tillage treatment), undisturbed soil samples were taken using an auger. The samples were collected from two depths 0-15 and 15-30 cm. These clods were weighed (W_1), dried, and after drying weighed again (W_2). The moisture content was calculated from the following equation, as proposed by Makki (2002):

$$moisturecontent\,(\%)=\frac{w_1-w_2}{w_1}\times 100\text{.........................}(9)$$

Where:

W_1 = moisture weight, g
W_2 = dry weight, g

Infiltration rate measurements

A double ring infiltrometer as described by Michael (1978) was used to determine the soil infiltration rate before and after tillage. The infiltrometer consisted of two concentric cylinders and a metering device (ruler). The infiltrometer was placed in a non-cracked area, and was hammered into the soil to a depth of 0.15 m using a hammer by striking on a short wooden to prevent damage to the edges of cylinders. The soil inside and outside the cylinders was formed to secure a good seal at the bottom and to enable the soil to settle back to its former condition. A piece of filter paper was placed inside the inner cylinder to serve as a protection against soil puddling and disturbance of the soil surface; and was removed carefully after water was added to the infiltrometer. The level of water was kept the same in both cylinders and was maintained by refilling to the same level (height). A graduated scale was used to measure the drop in water level. Readings were taken at five minutes intervals until they became constant. Measurements were taken before and after each tillage treatments and were replicated for each plot. The data was tabulated and the average infiltration rate (cm/hr) was determined.

RESULTS AND DISCUSSION

Effect of tillage type on field capacities

The result of the theoretical field capacity and effective field capacity of the disc and chisel plough are shown in Table (1). It can be seen that the chisel plough recorded the higher values of theoretical and actual field capacities (1.23 and 0.90 ha/hr respectively), compared to the disc plough which recorded a theoretical field capacity of 0.63 ha/hr and actual field capacity of 0.50 ha/hr. These results agree with the finding of Taj Elsir (2005) who found that the theoretical and actual field capacities recorded by chisel plough were 1.37 and 1.01 ha/hr respectively, while the disc plough recorded the lowest theoretical and actual field capacities of 0.28 and 0.20 ha/hr, respectively. The statistical analysis revealed highly significant difference between the values of theoretical and actual field capacities of the two treatments ($P \leq 0.01$). The highest theoretical and actual field capacities of chisel plough compared to disc plough mainly due to the large width of the chisel plough compared to the disc plough.

Effect of tillage type on field efficiency

The results of field efficiency of disc and chisel plough are shown in Table (1). It can be observed that the disc plough recorded the highest field efficiency (80%) compared to (72.6%) which was recorded by chisel plough. The result agrees with that obtained by Makki (2002) who obtained values of 82% and 75% for the field efficiency of disc and chisel plough respectively. The result in contrast with that obtained by Suliman

(2001) who stated that the chisel plough recorded the highest efficiency (89.9%) followed by disc plough (86.4%). The statistical analysis indicated that tillage implement type had significant effect on field efficiency ($P \leq 0.05$). The highest field efficiency of the disc plough as compared to the chisel plough may be attributed to low slippage of the disc plough.

Table 1: Implements theoretical field capacity, effective field capacity and field efficiency.

Implements	TFC (ha/hr)	EFC (ha/hr)	FE (%)
Disc plough	0.63	0.50	79.37
Chisel plough	1.23	0.90	73.4

Effect of implement type on slippage

The results of wheel slippage are shown in Table (2). It is clear that the chisel plough recorded higher slippage (14.01%) than disc plough which recorded (10.92%). This agrees with the finding of Taj Elsir (2005) who found wheel slippage of chisel plough of (12.91%) higher than that of the disc plough (7%) in the same experimental site. The result also agrees with that obtained by Dawelbaiet (1997) who valued the slippage of chisel and disc ploughs as 13.3 and 10.82% respectively. On the other hand, the result is in contrast with the result obtained by Makki (2002) who stated that the disc plough recorded the highest slippage (14.3%) followed by chisel plough which recorded (7.7%). This may be attributed to the difference in the operation depth and width of the two implements used in their studies. The statistical analysis of data showed no significant differences ($P \geq 0.05$) between the chisel and disc plough regarding tractor wheel slippage. The high slippage of chisel plough compared to the disc plough may be attributed to the higher width of chisel plough and to the greater depth of its operation.

When disc and Chisel Ploughs were used respectively

Effect of implement type on tractor fuel consumption

The results of implement type on tractor fuel consumption rate are shown in Table (2). It is clear that the highest fuel consumption rate (13.47 l/hr) was recorded by chisel plough compared to the disc plough of (10.6 l/hr). This agrees with finding of Taj Elsir (2005) who found that the fuel consumption rate of chisel plough (14.9 l/hr) is higher than that of disc plough (13.8 l/hr). On the other hand, the result does not agree with the result obtained by Suliman (2001), who stated that the highest fuel consumption rate (13.04 l/hr) was recorded by disc plough followed by chisel plough (10 l/hr). This may be attributed to the difference in the operation depth and width of the two implements used in their studies. The statistical analysis of data indicated that the differences in fuel consumption rate between tillage implements were significant ($P \leq 0.05$). The high fuel consumption rate when using chisel plough as compared to the disc plough may be due to the high draft and high slippage of the chiseling operation and may also be attributed to the high depth of operation in chisel plough.

Table 2: Effect of implements type on slippage and fuel consumption.

Implements	Slippage (%)	Fuel consumption (l/hr)
Disc plough	10.92	10.60
Chisel plough	14.01	13.47

Effect of tillage implements on soil physical properties:

Soil bulk density:

The results of the effect of tillage implements on soil bulk density are shown in Table (3). It can be seen that, generally, tillage operations resulted in reduction of the values of bulk density. Before tillage the values of soil bulk density were 1.54 g/cm^3 and 1.52 g/cm^3 for depth 0-15 cm and 15-30 cm respectively. These values were reduced to 1.51 g/cm^3 and 1.49 g/cm^3 when the disc plough and chisel plough were used at depth of 0-15 cm and further reduced to 1.49 g/cm^3 and 1.44 g/cm^3 at a depth of 15-30 cm. The statistical analysis showed no significant difference between the two treatments (disc and chisel plough) at both depths (P≥ 0.05). The result obtained agrees with result obtained by Makki (2002) who studied the effect of no-tillage, chisel and disc ploughing on some soil physical properties. He obtained values of 1.57, 1.52 and 1.53 g/cm^3 for the initial, chisel and disc ploughing respectively at a depth of 0-15 cm. The difference in bulk density between implements may be attributed to the difference in moisture content and compacting of soil by the disc plough.

Soil total porosity

The results of soil total porosity values (%) as affected by tillage implement are shown in Table (3). It is observed that the effect of implement type on soil porosity followed the same trend of its effect on bulk density. The lowest porosity values (40.2% and 40.7%) were recorded under no-tillage at depths 0-15 and 15-30 cm respectively. Chisel ploughing recorded the higher values (43.2% and 42.2%) at depths 0-15 and 15-30 cm, while disc ploughing recorded 41.3% and 41.1% at depths 0-15 and 15-30 cm respectively. From this result it is clear that soil porosity increases with increase in depth, and the highest porosity of chisel ploughing as compared to disc ploughing may be due to the effect of chisel in decreasing soil compaction. The statistical analysis showed no significant difference between the two treatments (P≥ 0.05). The result agrees with that obtained by Makki (2002), who stated that the lowest porosity of 41.13% and 35.71% were recorded, under no-tillage and disc plough respectively.

Infiltration rate of soil

The results of the effects of tillage implement on soil initial infiltration rate (cm/h) are shown in Table (4). It can be seen that the high initial infiltration rate (22.2 cm/h) was recorded for disc plough followed by chisel plough (21.6 cm/h), while no-tillage recorded the lowest value of infiltration rate (20.1 cm/h). However the basic infiltration rate showed values of 5.03, 4.86 and 3.1 cm/h under chisel plough, no-tillage and disc plough respectively. The result is in agreement with the result obtained by Makki (2002) who obtained values of initial infiltration rate of 24.9, 23.12, and 22.9 cm/h under disc plough, chisel plough and no-tillage respectively, in the same experimental site. The values of basic infiltration rate obtained were: 5.12, 3.96 and 2.88 cm/h under chisel plough, no-tillage and disc plough respectively. The superiority of chisel plough on basic infiltration rate over the other tillage systems was reported by Makki (2002). The statistical analysis showed no significant difference between tillage treatments (disc and chisel ploughing) on soil infiltration rate ($P \geq 0.O5$). The high infiltration rate of chisel plough as compared to disc plough may be attributed to depth the operation of chiseling.

Soil moisture content

The results of soil moisture content before and after application of tillage treatments are shown in Table (4). It can be seen that, the higher moisture content value (6.73%) was recorded for no-tillage, while disc and chisel ploughing recorded (6.3% and 6.53%) respectively at 0- 15 cm soil depth. The same trend was observed at a depth of 15-30 cm where no-tillage recorded highest moisture content (7.03%) while disc and chisel ploughing recorded (6.5% and 6.9%) respectively. The statistical analysis of data indicated no significant difference between the values of moisture content for different tillage implements ($P \geq 0.05$). The result agrees with the result obtained by Makki (2002) which comes in the following order; 11.9%, 15.53% and 15.83% for disc plough, chisel plough and no-tillage respectively. The high moisture content of disc plough as compared to chisel plough may be due to the soil inversion of the chisel plough and high compaction in disc plough and high penetration in chisel plough.

Table 3: Effect of tillage system and depth on Soil Bulk density (g/cm^3) and Porosity (%)

Tillage system	Bulk density (g/cm^3)		Porosity (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Disc plough	1.51	1.49	41.3	42.2
Chisel plough	1.49	1.46	42.2	43.2
Before tillage	1.54	1.52	40.0	40.7

Table 4: Effect of tillage system and depth on Soil moisture content (%) and Infiltration rate of soil (cm/h)

Tillage system	Soil moisture content%		Infiltration rate of soil cm/h	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Disc plough	6.3	6.5	22.2	22.2
Chisel plough	6.53	6.9	20.1	20.1
Before tillage	6.73	7.03	21.6	21.6

CONCLUSIONS

1) The higher theoretical field capacity (TFC) and effective field capacity (EFC) of (1.23 and 0.90 ha/hr) were recorded for chisel plough which also recorded the lower field efficiency (FE) of (73.4%) compared to the disc plough which recorded (0.63 ha/hr, 0.50 ha/hr and 79.37%) for TFC, EFC and FE respectively.

2) The higher fuel consumption of (13.47 l/hr) and higher wheel slippage of (14.01%) were recorded for chisel plough compared to the disc plough which recorded 10.60 l/hr and 10.92% for fuel consumption and wheel slippage respectively.

3) The lower bulk density was recorded for chisel plough which also recorded the higher porosity compared to the disc plough.

When disc and Chisel Ploughs were used respectively

4) Higher moisture content was recorded for chisel plough in 0-15 and 15-30 cm depth. Chisel plough also recorded the lower infiltration rate in both depths compared to the disc plough.

RECOMMENDATIONS

From the results obtained and conclusions drawn from this study, the following recommendations can be made:
1) More investigations needed to confirm the effects of disc and chisel plough on the physical and chemical properties of different type of soils.
2) For conventional ploughing at 20 cm depth, disc plough is recommended while for deep 25 cm and more chisel plough is recommended to break through and crack the hard soil.

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أداء المحراث القرصي والمحراث الحفار وتأثيرهما على بعض خصائص التربة الفيزيائية

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الخلاصة: اجريت هذه الدراسة بالمزرعة التجريبية لكلية الزراعة جامعة الخرطوم بشمبات لموسم (2007) لدراسة اداء المحراث القرصي والحفار وتأثير كل منهما علي بعض الخواص الفيزيائية للتربة. اوضحت النتائج ان القيم العالية للسعتين النظرية والفعلية تم تسجيلها بالمحراث الحفار (1.32 هكتار/ ساعة و 0.90 هكتار/ ساعة) مقارنة بالمحراث القرصي الذي سجل 0.65 و 0.50 هكتار/ساعة بينما تم تسجيل اعلي كفاءة حقلية بالمحراث القرصي (79.73%) مقارنة بالمحراث الحفار (73.4%). الوقود المستهلك بالمحراث القرصي (10.60 لتر/ساعة) وهو اقل من المستهلك بالمحراث الحفار (13.47 لتر/ساعة). وكان انزلاق عجلات الجرار اثناء الحرث بالقرصي (10.90%) و (14.1%) عند الحرث بالحفار. كذلك اوضحت النتائج ان استخدام كلا المحراثين يؤدي الي نقصان الكثافة الظاهرية للتربة من 1.54 جم/سم^3 الى 1.51 و 1.49 جم/سم^3 بالمحراث القرصي و الحفار على التوالي. لم تتاثر ($P > 0.05$) قيم كثافة الجزيئات للتربة عند استخدام المحراثين . زادت مسامية التربة باستخدام كلا المحراثين. سجل اعلي محتوي رطوبي (6.53% و 6.9%)عند العمقين 0- 15 و 15-30 سم للمحراث الحفار مقارنة بالمحراث القرصي الذي سجل (6.3% و 6.5%) للعمقين علي التوالي. كان معدل التسرب المتحصل عليه بالمحراث القرصي 22.2سم/ساعة بينما كان للمحراث الحفار 20سم/ساعة .