Performance Of Different Tillage Implements And Their Effects On Sorghum And Maize Grown In Gezira Vertisols, Sudan

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Abstract: Tillage practices have often been considered as limited factor to crop production in heavy clay soil. Experiments were conducted for two seasons (1998 and 1999) to investigate the effects of six tillage methods on sorghum and maize establishment and yield, weeds control and some soil physical properties. The technical performance of chisel plow and disc harrow was also investigated. Tillage methods comprehend chisel plow, disc harrow, disc plow and minimum tillage. Minimum tillage was significantly higher in all weed parameters compared to other methods. No significant differences were observed for crop establishment, plant population, total dry biomass, thousand seed weight and grain yield for both crops. Increasing the depth of chiseling and harrowing from 10 cm to 20 cm significantly (P<0.01) increased draft and drawbar power. Travel reduction under harrowing to 20 cm resulted in highly significant differences (P≤ 0.01) compared to other treatments. The effective field capacity, field efficiency and fuel consumption rates of chisel and harrowing at different depths of operation showed no significant differences. However, minimum tillage (ridging only) was the lease in fuel consumption and cost, 3.5 l ha-1 and 2 US$ ha-1, respectively. The above findings indicate that although all tillage methods gave fairly similar results in all tested parameters, minimum tillage could be recommended and adopted for sorghum and maize production in Gezira Vertisols as it was less expensive implement.

Index Terms: Disc harrow, Chisel plow, Maize, Sorghum, Tillage systems, Vertisols

1 INTRODUCTION

Low crop productivity is one of the major problems that are facing agricultural production in the Sudan. Low crop productivity in addition to high production costs, low prices and high taxes had all resulted in a general deterioration of the agricultural sector. This has contributed in converting agriculture from an attractive business to a repellent activity and caused many farmers to abandon agriculture and migrate to cities. The agricultural sector in the Sudan contributes to about 48% of the Gross Domestic Production (GDP) and to about 93% of the foreign currency earnings (Ministry of Finance and National Economy, 1996). It also employs about 65% of the labor force. Sorghum (Sorghum bicolor L.) is the major staple food crop in the Sudan. It is estimated that the annual consumption amounts to about 3.9 Million tons (Elsayed, 1999). It is cultivated in large areas that include both irrigated and rainfed. Farah, et al. (1997) reported that the area which is annually cultivated by sorghum is about 2.1 million ha, of which 80% is completely rain-fed, whereas the remainder is given supplementary irrigation throughout the growing season. The Gezira scheme contributes by 60% to the total irrigated production (Elsayed, 1999). Irrigated sorghum production is characterized by the use of disc harrows and ridgers for land preparation, improved varieties and fertilizers. However, yield per unit area in this sector is still very low 1400 kg ha^{-1} (Ibrahim, 1992). Great efforts had been put in the Gezira scheme to increase sorghum productivity which led to increase the average yield during the pervious seasons, this could be due to the high adoption rate of the recommended technical packages released by the Agricultural Research Corporation (ARC). Maize (Zea mays L.) is traditionally cultivated along the banks of the River Nile in the northern states and it is also cultivated in southern states. The area cultivated by maize in the Sudan during the period 1989-1995 is estimated to be about 21,840 hectares (FAO, 1995). However, maize is classified today as a new promising crop in the irrigated projects of central and eastern Sudan. The average yield per unit area of sorghum and maize of the Sudan are very low compared to other areas in the world have the same weather conditions. Vertisols of the Gezira scheme offers difficult physical environments to crop production, therefore, tillage is necessary to modify these environments to create optimum conditions for increasing sorghum and maize production. The objectives of this research were (1) to evaluate technically the performance of chisel plow and disc harrow, (2) to investigate the effects of different tillage methods on soil physical properties, weeds control, establishment, yield and yield components of sorghum and maize.

2 MATERIALS AND METHODS

2.1 Experimental Site

The Gezira scheme is characterized by a semi-arid climate. Annual mean air temperature is 28.0 ^{o}C, and monthly mean solar radiation ranges between approximately 20 and 26 MJm^{-2}, with the minimum occurring in July and December. Total precipitation is 280 mm (20 year average), almost all of which falls between July and October. Table 1 shows the major weather parameters from July through December for the study area (1971-2000). Dry spells occur during the rainy season, resulting in delaying crop growth.

TABLE 1

MONTHLY AVERAGE WEATHER CONDITIONS FOR THE STUDY AREA DURING SUMMER SEASON (1971-2000*)

Month	Mean Temp. (°C)	RH%	Wind speed (km/h)	Sunshine hours (hrs)	Rainfall (mm/month)
July	30.0	59	16.1	7.1	77.6
Aug	28.8	68	14.5	7.7	102.1
Sep	29.2	65	09.7	8.7	48.6
Oct	30.1	50	06.4	9.3	11.1
Nov	27.5	36	09.7	9.7	1.3
Dec	24.5	37	09.7	10.0	0.0

***Source:** *Sudan Meteorological Authority.*

2.2 Experimental Design and Cultural Practices

The experiment was arranged in a randomized block design with four replications. Each replication consisted of six tillage methods that were randomly assigned, the tillage treatments were chisel plow to 10 and 20 cm, disc harrow to 10 and 20 cm, disc plowing (plus light disc harrowing) and minimum tillage (no implement was used) all treatments were followed by ridging at 80 cm width. Sorghum and maize were hand sown using seed rates of 7.0 and 18.0 kg ha^{-1}, respectively, and planting was performed in the second week of July in both seasons and harvesting was performed during November. All other cultural practices were executed according to the recommendations from the ARC.

2.3 Soil Physical Properties

Soil bulk density was determined at two depths (0-10 cm, and 10-20 cm) four weeks from emergence and at harvesting in both seasons, soil bulk density was determined according to the method described by Blake and Hartge (1986). The soil samples were weighed, oven-dried at 105 °C for 24 hours, soil bulk density was determined using the following equation:

$$\text{soil bulk density}\left(\text{g cm}^{-3}\right) = \frac{\text{weight of soil sample}(\text{g})}{\text{volume of sample in }\left(\text{cm}^{3}\right)} \qquad (1)$$

Soil penetration resistance was measured using the proving ring penetrometer (Bradford, 1986) four weeks after emergence and at harvesting at a near field capacity of the soil. Data were collected and converted to kPa according to the manufacturer's conversion tables. The vertical intake of water was determined with a double-ring infiltrometer (Landon, 1984) before and after the application of the tillage treatments and at harvesting. The depth of the wetting front (cm) was determined after 3 hours using a steel rod pushed into the soil.

2.4 Soil Crop and Weed Measurement

For crop establishment and crop population, emerged plants four weeks after emergence and plant population at harvesting was estimated in ten meters square frame randomly taken from the two middle rows of each plot. Samples for total biomass and grain yield were taken from each plot with a sampling area of 32 m^2 (8 m x 4 m) for both crops. The yield and total dry biomass were expressed in kg ha^{-1}. For 1000 seeds weight, samples were taken randomly from harvested seeds of each subplot, the samples were weighed and the mean weight was obtained. On the other hand, weed population and percent ground cover were measured four weeks after emergence using 0.1 m^2 quadrant at six random positions per plot, two days before the scheduled weeding.

2.5 Performance of Chisel Plow and Disc Harrow

Technical performance was conducted to compare chisel plow, the newly introduced implement in the irrigated schemes, and the disc harrow the widely used in the Gezira scheme, the comparison included measurement of draft, travel reduction (slippage), drawbar power determination, measurements of actual field capacities and efficiencies, and measurement of fuel consumption rates. For draft measurement, two tractors with the same horse-power were used as a test and auxiliary to estimate draft requirement for the chisel and the tandem disc harrow using hydraulic dynamometer at the assigned depths (10 cm and 20 cm), the measurements were performed according to Bukhari et al. (1992). The travel reduction of the tested tractor was determined by marked the rear wheel at a portion tangent to the ground surface, then distance travel in 10 revolutions with load and without load were marked and measured. The travel reduction was calculated using the formula described by Barger et al. (1963):

$$\text{Travel Reduction} = \frac{(\text{Distance with no pull} - \text{Distance with pull})}{Dis\tan ce \text{ with no pull}} \qquad (2)$$

Drawbar power is defined as a power actually required for pulling or moving the implement at a uniform speed. The drawbar power exerted by the tractor on the implement was calculated using equation of Kepner et al. (1978):

$$Dbp = D \times S / 3.6 \qquad (3)$$

where Dbp is the drawbar power in kW, D is the implement draft in kN and S is the tractor speed in km h^{-1}. For actual field capacity and efficiency, an area of 10080 m^2 (280 x 36 m) was selected as a test plot to measure machine capacities and efficiencies. At the same plot fuel consumption was carried out using an auxiliary tank attached to the fuel pump of the tractor and the amount of fuel used was recorded from the scale of auxiliary tank in liters at the beginning and end of the test plot.

3 RESULTS AND DISCUSSIONS

3.1 Weed Control

Results in Table 2 shows the measured weed parameters during the two seasons (1998 and 1999). The analysis of variance showed no significant differences (P<0.05) between different tillage methods during the first season. In the second season significant differences in total number of weeds at (P<0.05) and percent ground cover at (P<0.01) were observed. The disc plowing and chiseling to 20 cm depth resulted in significantly lower total number of weeds compared to the minimum tillage (100 per m^2). Minimum tillage gave highly significant (P<0.01) in percent ground cover (25%) when compared to chiseling at both depths, harrowing to 10 cm and disc plow treatments. Chiseling and harrowing implements work the soil deeper than minimum tillage, thereby resulting in a better weed control reflected in lower weed population. It is clear from Table 2 that the total number of weeds during the second season was about half that of the first season. This may be due to a combined effect of tillage and herbicides of the pervious cotton crop. The higher weed infestation recorded for minimum tillage method compared to chisel and disc implements might be attributed to the manipulation and inversion of the soil, similar observations have been reported by Dawelbeit and Salih (1994).

3.2 Soil Bulk Density

Table 3 shows the results of soil bulk density measured 4 weeks after planting and at harvesting at upper 20 cm depth. The statistical analysis showed that there were no significant differences (P<0.05) in the effect of tillage on this parameter. However, soil bulk density increased with increase of depth. Results also indicated that, soil bulk density decreased after tillage methods compared with that before tillage. It worth to mentioned that soil bulk density values measured before tillage found to be around 1.34 and 1.42 g cm^{-3} at depths of 0-

10 cm and 10-20 cm, respectively. These bulk density values increase as the season progresses. This could be due to drying and wetting of the soil caused by irrigation cycles.

Table 2. Total number of weeds and percent ground cover during 1998 and 1999 seasons

Treatment	Total weeds per m^2		% ground cover	
	98	99	98	99
Chisel 10 cm	148a	94ab	29a	19b
Chisel 20 cm	146a	52b	27a	12c
Harrow 10 cm	159a	68ab	24a	19b
Harrow 20 cm	155a	91ab	30a	23ab
Disc plow	129a	51b	20a	12c
Minimum tillage	172a	100a	34a	25a
Mean	152	76	27	18
L.S. ‡	n.s	*	n.s	**

Means followed by the same letter (s) in the same column are not significant at P ≤ 0.05 and P ≤ 0.01 for 1999 according to Duncan's multiple range test. L.S. is level of significant.

Table 3. Soil bulk density (g cm^{-3}) at different tillage methods

Treatment	Firs season 1998			
	4 week after planting		At harvesting	
	0 – 10	10 – 20	0 – 10	10 – 20
Chisel 10 cm	0.96a	1.06a	1.03a	1.16a
Chisel 20 cm	0.98a	0.95a	1.03a	1.23a
Harrow 10 cm	0.97a	1.04a	0.99a	1.21a
Harrow 20 cm	0.98a	1.04a	1.08a	1.16a
Disc plow	0.97a	1.02a	1.04a	1.23a
Minimum tillage	1.03a	1.04a	1.09a	1.21a
Treatment	Second season 1999			
Chisel 10 cm	1.13a	1.21a	1.15a	1.20a
Chisel 20 cm	1.00a	1.14a	1.19a	1.19a
Harrow 10 cm	1.12a	1.24a	1.10a	1.24a
Harrow 20 cm	1.07a	1.24a	1.13a	1.27a
Disc plow	1.14a	1.22a	1.22a	1.26a
Minimum tillage	1.11a	1.27a	1.22a	1.36a

3.3 Soil Penetration Resistance

Table 4 shows the mean values of penetration resistance (kPa) four weeks after planting and at harvesting during 1998 and 1999 seasons. Readings were taken from the upper soil depths (0-20 cm) with 10 cm increment for each tillage method. In the first season the analysis of data showed significant differences in the penetration resistance measured after 4 weeks after planting at the two depths (0-10 cm and 10-20 cm).

Table 4. *Soil penetration resistance (kPa) at different tillage methods*

Treatment	Firs season 1998			
	4 week after planting		At harvesting	
	0 – 10	10 – 20	0 – 10	10 – 20
Chisel 10 cm	255b	325b	327a	387a
Chisel 20 cm	275ab	350b	323a	413a
Harrow 10 cm	300ab	375ab	307a	593a
Harrow 20 cm	250ab	350ab	323a	463a
Disc plow	275ab	450a	310a	527a
Minimum tillage	325a	450a	307a	637a
L. S. ‡	*	**	n.s	n.s
Treatment	Second season 1999			
Chisel 10 cm	404a	448a	350a	493a
Chisel 20 cm	388a	455a	327a	445a
Harrow 10 cm	454a	499a	395a	560a
Harrow 20 cm	395a	470a	350a	467a
Disc plow	441a	495a	328a	467a
Minimum tillage	459a	500a	355a	483a
L.S. ‡	n.s	n.s	n.s	n.s

Minimum tillage gave significantly higher penetration resistance at 0-10 cm ($P<0.05$) and 10-20 cm ($P<0.01$) compared to chiseling to 10 cm and disc plow, respectively. However, results on harvesting time and second season showed no significant differences between tillage methods at the two depths. Furthermore, significant lower soil penetration resistance of chiseling was judged to be due to soil loosening effect of primary and secondary tillage implements used. Table 4 shows that soil penetration resistance increased at the end of the season than that after tillage methods. This could be attributed to high bulk density at the end of the season. Results obtained in soil penetration resistance confirm the fact that the improvement of soil physical parameters due to tillage on a heavy clay soils seems to be short-lived (Simpson and Gumbs, 1985). These findings also confirm reports by Abdalla (1984) that the initial soil resistance to penetration was markedly reduced by tillage methods.

3.4 Infiltration Rate

Infiltration rates measured after tillage methods and at harvesting are shown in Fig. 1. infiltration rate measured at 5 minutes through 3 hours was higher under tilled soil compared to that before tillage (control). The curve after tillage followed the shape described by Baver (1972), infiltration rate was high after 5 minutes then decreased rapidly as time progresses till it approaches a constant rate after 2 h. The initial infiltration rates were greatest for disc implements compared to chisel plow, but at harvesting time the rate was decreased and was less than after tillage. Crop production practices and subsequent irrigation tend to destroy natural channel of the soil. However, at harvesting, chiseling to 20 cm gave higher infiltration rate after 10 minute (Fig. 1B), this fact explains that chisel has long-term effect on soil compared to other implements, which may impact the growth of the following crop in the rotation.

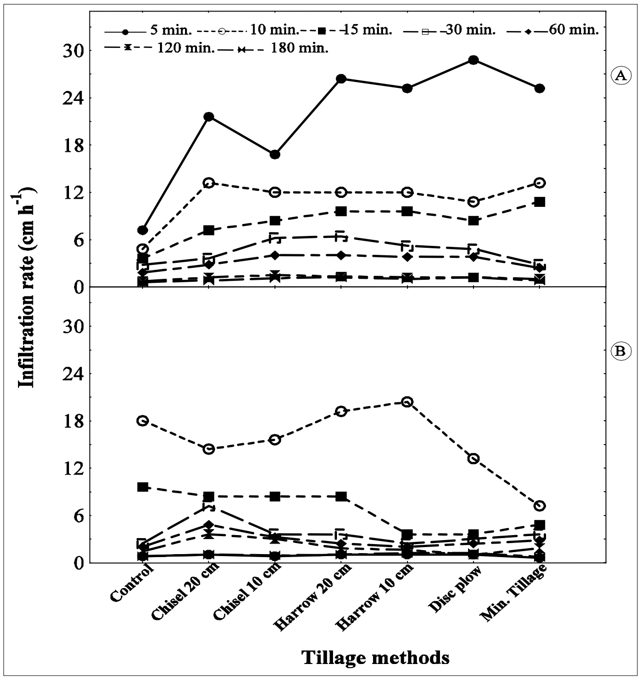

Fig. 1. Infiltration rate (cm h-1) after tillage method (A) and at harvesting (B)

Figure 2 shows the depth of wetting front both after tillage and at harvesting time. Chiseling to 20 cm gave significantly higher depth of wetting front after tillage and at harvesting, however, increasing the depth of tillage increased the depth of wetting front for both chisel plow and disc harrow. Chiseling is more efficient than harrowing to improve soil physical properties in term of infiltration rate (Fig. 2).

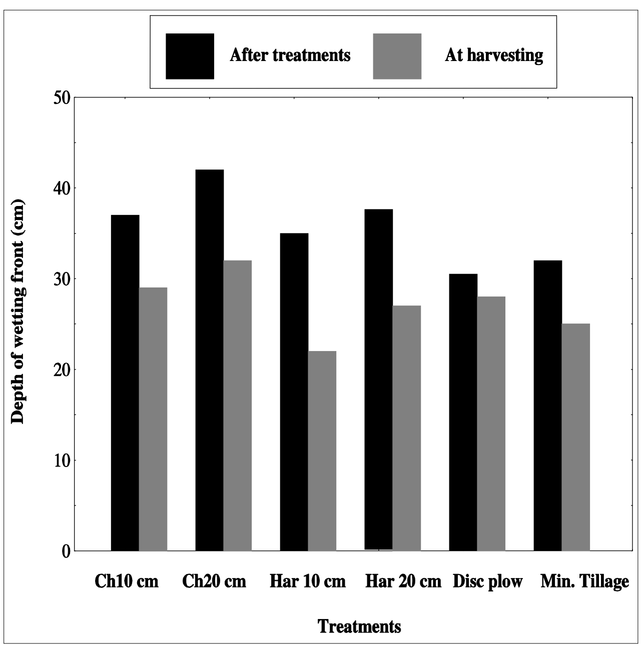

Fig. 2. The depth of wetting front (cm) after tillage methods and at harvesting time.

It was observed that values of infiltration rate and depth of wetting front at harvesting time tend to approach the values which were obtained before tillage (control). This may be due to the fact that clay soil returns to its former state because of subsequent irrigation and different cropping practices.

3.5 Yield and yield components

Data of crop establishment, plant population, total dry biomass, thousand seed weight and grain yield of sorghum and maize are presented in table 5. Analysis of variance showed that no significant differences ($P<0.05$) were observed in sorghum and maize in both seasons. It was observed that plant population, total dry biomass and yield of sorghum in the first season were higher than that in the second season, while for maize total dry biomass, grain yield and thousand seed weight were higher in the second season than that in the first season. Similar results obtained under different tillage systems for both sorghum and maize confirm the fact that sorghum and maize are less sensitive to tillage under Gezira Vertisols. Results were in agreement with findings reported by Dawelbeit and Salih (1994). Considering the fact that all tillage methods gave similar results in term of crop yield and yield components of sorghum and maize, minimum tillage (ridging only) was the least in fuel consumption and cost compared to its counterparts. Thereby, it could be recommended and adopted for sorghum and maize production in the heavy clay soil of Sudan.

3.6 Performance of chisel and disc harrow

3.6.1 Draft

The mean draft values for chisel plow and disc harrow at different depths are summarized in table 6. Draft readings were taken in firm soil with mean soil moisture content 8.6% (dry base). Statistical analysis showed highly significant differences ($P<0.01$) between chisel and disc harrow. Chiseling to 20 cm depth obtained the highest draft (4.95 kN m^{-1} width) which was higher by 35.6% from chiseling to 10 cm and by 65.5% and 35.6% from harrowing to 10 cm and harrowing to 20 cm, respectively. Results indicate that draft increases with increases in depth, this agreed with Igbal et al. (1994). They reported that a linear relationship existed between draft and depth of operation. It was observed that in the firm tested soil the chisel plowing resulted in higher draft than the disc harrowing, which may attributed to the effect of the vertical portion of the chisel shanks below the ground surface (Kepner et al., 1978).

3.6.2 Travel reduction

Slippage is defined as the travel reduction of the drive wheels. Slippage of a tractor's drive wheels wastes power and fuel and affects the traction efficiency of the pulling machine. Table 6 shows the means of travel reduction for both chisel and disc harrow. Statistical analysis showed highly significant differences at ($P<0.01$) between the treatments. However, harrowing to 20 cm resulted in highly significant travel reduction compared to other treatments. Results also showed that travel reduction increased with the increase in depth for both implement types. Travel reduction for chisel plow increased slightly around 12.5% when the depth of operation increased from 10 to 20 cm, however, a greater increase (62%) took place when the depth of disc harrowing was increased from 10 cm to 20 cm.

3.6.3 Drawbar power

Drawbar power is defined as the actual power required pulling or moving the implement at a uniform speed. Table 6 shows the mean values of the tested implement under two depths of operation. Analysis showed that highly significant differences (P<0.01) between treatments. Chiseling to 20 cm depth gave the highest drawbar power (4.38 kN m^{-1}) which was 39.5%, 60.5% and 25.8% more than chiseling to 10 cm, harrowing to 10 cm and harrowing to 20 cm respectively.

Table 5. *Effects of different tillage methods on yield and yield components of sorghum and maize during seasons 1998 and 1999*

Treat.‡	Plant estab./m^2		Plant pop./m^2		Biomass (kg ha^{-1})		Yield (kg ha^{-1})		1000 seeds wt (g)	
	98	99	98	99	98	99	98	99	98	99
Sorghum										
Ch10	11a	9a	9a	5a	9579a	6457a	3531a	2062a	23a	24a
Ch20	11a	9a	8a	4a	9952a	6169a	3736a	2229a	24a	20a
Har10	10a	9a	8a	4a	9952a	6812a	3469a	2229a	24a	23a
Har20	9a	9a	8a	5a	10321a	6812a	3921a	2229a	23a	20a
DP	9a	9a	7a	4a	10517a	6126a	3726a	2043a	23a	21a
MT	10a	9a	8a	4a	9907a	6493a	3736a	2021a	24a	22a
C.V.%	13.7	11.7	19.9	11.1	15.6	13.2	18.2	10.0	7.4	14.1
Maize										
Ch10	11a	4a	3a	4a	2376a	7367a	1114a	3219a	190a	579a
Ch20	11a	4a	3a	4a	2843a	7219a	1114a	3421a	182a	282a
Har10	11a	4a	3a	4a	2491a	6945a	1045a	3312a	187a	281a
Har20	9a	4a	3a	4a	2552a	7298a	1264a	3438a	185a	283a
DP	9a	4a	2a	4a	2141a	7695a	936a	3369a	173a	242a
MT	9a	4a	2a	4a	2291a	7617a	1005a	3610a	193a	277a
C.V.%	14.5	11.6	31.8	12.6	40.7	14.2	39.9	16.1	12.4	15.8

The simple correlation analysis for chisel plowing showed that draft accounts for about 89.6% in variability of drawbar power, speed accounts for 9.5% while draft and speed jointly account for 99.1%. For disc harrow the correlation showed that draft accounts for 93.8% in variability of drawbar power and speed accounts for 5.7% while draft and speed jointly account for 99.5%. It can be concluded that drawbar power positively affected by the draft and negatively by the speed.

3.6.4 Effective field capacity and efficiency

Table 6 represents the effect of soil depth and implement type on effective field capacity and field efficiency. Statistical analysis showed that there were no significant differences (P<0.05) between implements. This was evident because the same prime mover (Tractor) was used for all the treatments. Furthermore, the same chisel plowing and disc harrowing were compared at two depths. Results revealed that increasing depth of tillage as well as changing implement did not change field capacity and field efficiency.

3.6.5 Fuel consumption and cost of operation

The mean values of fuel consumption rate in liter per hectare (L ha^{-1}) and cost of operation (US$ ha^{-1}) were summarized in Table 7. Results showed that significant differences (P<0.01) were observed between implements. The highest fuel consumption of 15 l ha^{-1} was obtained by disc plow, However, chisel plow and disc harrow showed similar values (11.9 and 12.7 l ha^{-1}), which might be due to the more power available in the tractor engine than the draft required by these implements. In contrast, minimum tillage (ridging only) obtained the lowest fuel rate (3.5 l ha^{-1}). The amounts of fuel consumed by the tractor under different implements were in the range reported by Ahmed and Haffar (1993) in the Rahad scheme, Sudan. These results are also in line with the results reported by El-Awad, (2000) in a heavy clay soil in Sudan. Chiseling and disc implement (disc harrow and disc plow) resulted in the highest cost, while minimum tillage (ridging only) resulted in the least (Table 7). In chiseling and disc implements, the soil has to be ploughed deeply and this coupled with the high rates charged for tractor services resulted in the highest cost than minimum tillage (ridging only).

Table 6. *Effect of working depth and implement type on draft (D), travel reduction (TR), drawbar power (Dbp), effective field capacity (EFC), and implement efficiency ‡*

Treatments	D (kN m^{-1})	TR (%)	Dbp (kW m^{-1})	EFC (ha h^{-1})	Efficiency (%)
Ch 10 cm	3.19c	8.5b	2.65b	1.49a	82.9a
Ch 20 cm	4.95a	9.7b	4.38a	1.35a	74.9a
Har 10 cm	1.71d	6.8b	1.73b	1.90a	75.5a
Har 20 cm	4.06b	17.8a	3.88a	1.75a	69.5a
C.V.%	12.6	22	23.4	10.2	9.2
L.S. ‡	**	**	**	n.s	n.s

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Table 7. *Fuel consumption rate and cost of different tillage implements*

	Ploughing depth (cm)	Fuel consumption (l ha^{-1})	Cost (US$ ha^{-1})
Chisel plow	20	11.9a	7a
Disc harrow	20	12.7a	7a
Disc plow	20	15.0a	8a
MT (ridging only)	15	3.5b	2b
L.S.		**	**

4 CONCLUSION

From this research the following points could be concluded: Disc implements (disc harrow and disc plow) were found to be slightly effective in controlling weeds than chisel plow. Minimum tillage (ridging only) was always the least effective in controlling weeds. All tillage methods resulted in similar effects on soil bulk density and penetration resistance. However, in the first season minimum tillage resulted in significantly higher penetration resistance 4 weeks after planting. All tested tillage implements were found to improve water infiltration rate and the depth of wetting front when compared to non-tilled soil. However, chiseling has more pronounced effect even at harvesting. All tillage systems showed similar effects on yield and yield components of sorghum and maize in the Gezira Vertisols. However, minimum tillage (ridging only) was less expensive and could be recommended for sorghum and maize production. Chisel plow requires higher draft and higher drawbar power compared to disc harrow, while disc harrow to deeper depth (20 cm) resulted in higher wheel slippage than chisel plow. Chisel plow and disc harrow obtained similar effective field capacity, filed efficiency and fuel consumption rates.

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