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Performance of soil moisture retention and conservation tillage techniques as indicated by sorghum (*Sorghum bicolor* L. Moench.) yield and yield components

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ABSTRACT

A study was conducted to investigate the effect of different tillage techniques as zero-tillage (ZT), chisel plowing (CP) compared the conventional plowing method using wide level disc (WLD) on water conservation parameters, soil moisture status within the root zone (60 cm depth) throughout the season (at early, mid and late season), initial infiltration rate, time to reach final water intake rate, precipitation use efficiency, yield and yield components of sorghum crop, under rain-fed conditions. It showed that conservation tillage techniques gives better results with respect to the parameters studied i.e. soil moisture content, grain yield, dry matter yield, and other yield components such as plant height, plant population, days to 50% flowering.

Key words: soil moisture, conservation tillage techniques, sorghum (*Sorghum bicolor* L. Moench.), grain and dry matter yield, yield components.

Introduction

About 95% of world agricultural land and 83% of world cropland depends on precipitation as the sole source of water (Wood *et al.*, 2000). Food security and poverty alleviation, main objectives of all development efforts, can only be achieved if sustainable land and soil management practices are applied on a large scale.

In Sudan 0.84 million ha are cultivable land or suitable for agriculture (Buraymah, 2000). Of the total cultivable land, rain-fed agriculture occupies about 15 million ha; of which 9 million ha are in the traditional agriculture (TA) while the rest in the mechanized agriculture (MA).

Gedaref State lies in the eastern part of Sudan covering an area of 71,000 km², it lies between latitudes 12.67° and 15.75° N and longitudes 33.24° and 37.00° E. The State extends from north to south covering three climatic zones (van der Kevie 1973). Climate characterized by higher summer temperatures and warm winters. Rainfall is always in the summer, and most of the rain falls within the period of May to October. Seasonal rainfall ranges from 200 mm in the arid area at the far northern areas to 800 mm in the savannah zone at the far southern areas. This rainfall status, together with the suitable nature of the dark cracking soils (Vertisols) throughout the area make this state to be the main area in rainfed crop production in Sudan. Grain production shortfalls in central Sudan are commonly associated with occurrence of intra-seasonal dry spells or droughts and rapid land degradation which adversely impact crop yields. Suitable practices that use available rainwater more efficiently to mitigate impact of dry spells on crops and that protect soil are needed to stabilize and improve grain yields in the predominately rainfed agriculture. One possible option to conserve soil moisture and limit soil erosion in the root zone of rainfed Sorghum crop (*Sorghum bicolor* L. Moench) is to employ effective tillage operation. There are wide ranges of possible tillage machines to use. Then the dilemma is to choose the most optimum one. The criteria used to select the effective tillage machine are reported to include infiltration rate, soil moisture storage, precipitation efficiency and crop yield and yield components.

There is much discussion about the effect of tillage on soil moisture conservation. Tillage is good for water infiltration and root penetration, as the soil is worked into clods. However, this is only true for stable soils. If the soil is less stable, the clods will disappear rapidly when it rains. Tillage is required on badly degraded soils or for those that undergo severe hardening during the dry season. Deep tillage (disturbing the soil below 10 cm) has proven beneficial on dense sandy soils in Botswana. However, repeated cultivation to the same depth may

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cause a compacted soil layer to form at the bottom of the tilled layer (called a 'plough-pan', or 'hoe-pan' etc.). Plant roots cannot penetrate into this layer and the water storage capacity of the soil is reduced. In this case, when the clogged layer is several tens of centimeters below the surface, chisel plowing is necessary to increase infiltration. Some soils become crusted over on the surface when it rains, especially soils containing much clay and silt. This leads to a low infiltration rate and a high rate of runoff. In this case, with crusted soils, when the soil pores are clogged in the first few millimeters or centimeters, hoeing or superficial plowing is sufficient to break up the crust and let the water infiltrate.

The rationale behind adopting tillage techniques on water conservation parameters is that:

The tillage system that develop more porosity is expected to have high soil moisture status within the root zone (60 cm depth) throughout the season (at early, mid and late season) compared to one developing less pore space. High initial infiltration rate indicate more water storage capacity. Infiltration of water into a soil is improved by making the soil structure looser and the top layer rougher. This can be achieved through the use of different tillage techniques. Less time to reach final water intake rate reflect fast water movement into soil body due to creation of inter-spaces by tillage technique. Precipitation use efficiency is an indicator of more efficient water utilization and minimum water losses as surface run off. High yield and improved yield components of sorghum crop, under rain-fed conditions are usually constraint by conservation of moisture within the soil root zone.

Tillage is defined as the mechanical manipulation of soil for any purpose. Manipulation involves soil disturbance and this can have great deteriorative consequences if not carefully or adequately incorporated. Tillage modifies the soil surface where the complex and crucial partitioning of rainfall into runoff, infiltration and subsequent evaporation occur (Mwendera, 1992).

Tillage systems affect the amount of water moving both over the surface and through the soil. Moldboard or other inversion types of plowing increase the rate at which water moves into soil over the short term. However, after several rainfall events, a crust often forms at the surface, reducing infiltration rate. The highest runoff and sediment losses were observed for conventional tillage. Runoff rate is inversely related to soil infiltration rate (Rockwood and Lal 1974). Studies by Lindstrom and Onstad (1984) showed a higher runoff volume for no-tillage as compared to conventional tillage. Conservation tillage reduces soil losses (Blevins et al. 1990), but does not always reduce the volume of runoff as effectively as it reduces sediment losses.

Surface residues, as with conservation tillage systems, reduce runoff (by 1.2 to 2.2 %) and increase infiltration than ploughed soil (by 8.3 to 21.5 %) at 1 and 15% slope respectively (Rockwood and Lal 1974). Tillage studies on silt soils in Germany showed that, no tillage improved soil structure due to increased concentrations of organic matter in the surface, resulting in less slaking during heavy rains (Ehlers 1979). Even though total porosity was increased by tillage, the macro pores connecting the soil surface to the subsoil were enhanced, thus improving infiltration. Water infiltration increases with increasing amounts of residue on the surface (Lang and Mallett 1984). Zero tillage resulted in lower infiltration rate while disc plow tillage recorded higher infiltration rate (Subbulakshmi 2007).

As reported by Unger (1981) in an irrigated winter wheat fallow-dry land sunflower system, average increases in soil water content during fallow after wheat were 38, 53, 61, and 71 mm with disk, sweep, limited (sweep tillage plus herbicides) and no-tillage treatments, respectively (Unger 1981). The study conducted by Unger and AcCalla (1980) showed that, soil water storage was 29, 34, 27, 36 and 45 % under mouldboard, disc, rotary, sweep and no tillage treatment respectively.

Smika (1976) compared the effects of conventional, minimum and no-tillage treatments on soil water loss during a 34 day period following 165 mm of rainfall, during which no additional rainfall occurred. On the day after the rainfall, soil water contents to the 15 cm depth were similar for all treatments. At 34 days, soil with the conventional tillage treatment had dried to less than 0.1 cm cm^{-1} to 12 cm depth and the minimum tillage soil had dried to that water content to 9 cm depth. In contrast, soil with the no-tillage treatment dried to the 0.1 cm cm^{-1} water content only to 5 cm depth. No till can improve infiltration, reduce erosion, and increase yield as a result of natural processes acting to improve soil quality (Lal, 1985, 1998; Pala *et al.*, 2000; Dominy and Haynes, 2002; Wahl *et al.*, 2004).

Chisel plow is a subsoil cultivation technique that cuts soil deeper than achieved with conventional tillage. Chisel plow improves grain yield by enhancing root growth and infiltrating more rainfall deeper in the soil profile particularly in soils with compacted low permeability sub-layers (Salih *et al.*, 1998; Abu-Hamdeh, 2003; Pikul and Aase, 2003; Xu and Mermoud, 2003; Birkas *et al.*, 2004; Pagliai *et al.*, 2004). Hardpans and soil compaction caused by repeated tillage to the same depth for generations has been reported (Mwendera and Mohamed Saleem, 1997), but little is known about their prevalence in dry lands and the level of impact on agricultural yield.

Zero-tillage (ZT) is defined as a tillage/planting system where the soil is left undisturbed from harvest to the next season planting. Planting is accomplished in a narrow seedbed or slot created by coulters, row cleaners, row chisels or roto-tillers. Weed control is accomplished primarily with herbicides. Less than 25% row width disturbance is considered no-till. No-tillage is a method of crop production that involves no seedbed preparation

other than opening the soil for the purpose of placing seed at the desired depth (SCS 1982). Under moderate intensity rainfall, zero tillage decreased yield by 25%, and under high intensity rainfall events, sub-soiling had the best sorghum yield with 42% increase over the control (1430 kg ha^{-1}). The results obtained by zero tillage were attributed to the existence of hard soil resulted in poor root growth and plant establishment which, in addition to the increased weed infestation, explain the poor grain and biomass production. Although zero-tillage sometimes decreases grain yields during the first season of implementation, but after several years of cropping with better-adapted management techniques yield increases have been observed (Lal, 1998; Pala *et al.*, 2000 and Astatke *et al.*, 2003). Continuous zero tillage practice would result in a high yield response in the coming years by improving soil physical and chemical conditions (Jin *et al.*, 2007).

Matocha *et al.* (1997) concluded that method of primary tillage usually has little or no effect on final grain yields except in droughty seasons when yield reductions were associated with deep primary tillage with either moldboard or chisel plows. A minimum tillage system developed for southern Texas produced 110% of the conventional tillage system corn yields in seasons with sub-average precipitation and 101% with above average precipitation.

Morrison (2002) concluded that strip tillage appears to be an improvement over strict no till for the soil types in the study, in terms of corn growth and yield. Both deep and shallow types of strip tillage increased corn growth and yield in some cases over conventional chisel plowing and tandem disking tillage, but there was no advantage to the use of the deeper knife chisel over shallow sweep strip tillage in the soils tested. Rashidi *et al.* (2010) concluded that among three methods of tillage imposed, the conventional tillage (CT) method was found to be better over the minimum tillage (MT) and no-tillage (NT) methods in achieving higher yield of tomato through improving plant population density (PPD) and number of fruits per plant (NFPP). Reduced soil penetration resistance, reduced soil bulk density, increased soil moisture preservation, enhanced root-soil contact and better weed growth suppressing might have helped in retaining good PPD and NFPP, and resulted in higher yield in conventionally tilled plots. Further long-term studies are needed to find the beneficial effects of no-tillage on soil quality and yield when it is supplemented with extra nutrients or crop residue.

Some authors have thus ascertained no differences in cereal production between tillage systems (Unger, 1994; Schillinger, 2001), other researchers observed greater soil water storage under no-tillage and thus better crop yields and water use efficiencies (Lawrence *et al.*, 1994; Bonfil *et al.*, 1999). Moret *et al.* (2001) concluded that there were no clear differences in crop yield among tillage treatments for the study period. This finding suggests that conventional tillage can be substituted by conservation tillage for fallow management in semiarid dryland cereal production areas in central Aragon (Anschütz, *et al.* 2003).

Since 1945, the wide level disk (WLD) with seeder box constitutes the lonely machine used for sorghum cultivation in all mechanized farming areas of the Sudan. Yousif (2001) stated that continuous use of WLD is believed to have led to the deterioration of the soil physical properties and may have created a hard pan at the depth of cut. This in turn had resulted in decreased water infiltration rates, reduced crop root growth, caused water runoff and decreases the yield of sorghum (Salih and El Amin, 1986). Inaccurate seeding depth, with seeds often placed too deep or too shallow thus causing uneven emergence and randomly scattered and patchy stand. These scattered plants make it impossible to control weeds with an inter row cultivator. Moreover, manual weeding of scattered plants usually results in decreasing the plant stand by unintentional eradication of the crop.

Efficiency is generally defined as the non-dimensional ratio of output over an input. Some authors referred to it as a non-dimensional output/input ratio. Duivenbooden *et al.*, (2000) defined WUE as the ratio of the amount of water used to achieve a given output. All types of water use were being evaluated; rainfall, (evapo-) transpired water, irrigation water, etc. and the type of output vary according to the objectives of the evaluation process. PUE may therefore refer to crop yield per unit rainfall, total biomass per unit irrigation water (IWUE) or mass of hydrocarbons stored per unit water transpired (Duivenbooden *et al.*, 2000). As a consequence, WUE had been replaced with more specific definitions such as precipitation use efficiency (PUE), irrigation water-use efficiency (IWUE), transpiration efficiency (TE), etc., and the calculation procedures should be clearly explained. PUE may therefore refer to crop yield per unit rainfall as:

$$\text{PUE} = Y/R \quad (2.1)$$

Where:

PUE: is the precipitation use efficiency (Kg/ ha.mm),

Y: is the crop yield (Kg/ha),

R: is the seasonal rainfall (mm).

Hemmat and Eskandari, (2006) reported that, PUE is significantly influenced by tillage systems. Zero tillage technique with total residue management reached a significantly higher PUE level than conventional management when averages across years and over tillage system. During the drought, much of the precipitation was used to grow the plant, while in the wet year; the increased precipitation resulted in a greater portion of the water being used to produce grain. The same trend was also observed in dry and wet years by Cochran *et al.*, (1982). In contrast, Jin and Junjie (2007) found that sub-soiling resulted in higher yield and PUE compared with

conventional and zero tillage which was attributed to a slightly better infiltration after sub-soiling and the breaking up of the continuity of flow paths in the soil, while the soil compaction in ZT adversely affects soil properties, resulting in a relatively lower PUE compared to sub-soiling (Lipiec and Hatano, 2003).

Yousif *et al.* (2009) found that in the vertisols of the mechanized rainfed agricultural sector in the Northern region of Gedaref state, Sudan, the effects of tillage methods on soil moisture content and sorghum grain yield were that no significant difference in soil moisture content among the different tillage methods. The wide level disk plowing resulted in a consistent yield throughout the two seasons compared to other tillage treatments. Zero tillage and chisel plowing resulted in a significantly higher sorghum grain yield in the first season and combined analysis. The tested tillage methods were; chisel plowing (0.20 m), moldboard plowing (0.20 m), disk harrowing (0.09 m), wide level disk plowing (0.07 m) and zero-tillage.

Farmers in the MA use one to three runs with the wide level disk (WLD) plowing for pre-sowing weed control, seedbed preparation and seeding. The continuous tilling of the soil to a constant depth (5 to 8 cm) for more than fifty years was believed to result in soil compaction, resulting in lower crop yields. Results of experiments in rainfed agriculture in Gedaref State showed that sub-soiling and harrowing increased sorghum grain yield significantly over the traditional method (Salih and El Amin, 1986). However, the use of tillage on vertisols when cracks are open had an adverse effect on the soil moisture content in the rainfed areas (Saeed, *et al.*, 2005).

In zero-tillage system, seeding is done with no preliminary tillage, by the use of a planter which has special furrow openers, disk covers and packer wheels to obtain the desired seed placement (USDA, 1994). Research on rainfed Vertisols showed that the use of no-till, offset disk harrow and chisel as post harvest tillage treatments had no significant effect on sorghum establishment and grain yield (EL Ghali, *et al.*, 1992). However, Taha *et al.*, (2005) reported that, zero-tillage gave significantly higher sorghum grain yield compared to conventionally tilled seedbed. Also, Ahmed *et al.* (2004) reported that fallow managed seedbed resulted in higher sorghum grain yield compared to conventional tilled seedbed.

The main objective of this study is to investigate the effect of different tillage techniques such as zero-tillage (ZT), chisel plowing (CP) compared to the conventional plowing method using wide level disc (WLD); on water conservation parameters, namely soil moisture status within the root zone (60 cm depth) throughout the season (at early, mid and late season), initial infiltration rate, time to reach final water intake rate, precipitation use efficiency and yield and yield components of sorghum crop under rain-fed conditions.

Materials and Methods

An experiment was conducted at the Demonstration Farm of the Faculty of Agricultural and Environmental Sciences, University of Gedaref at Twawa area (Long. 35.24° E, Lat. 14.02° N and altit. 602 m AMSL) for two consecutive seasons in 2006/07 (FS) and 2007/08 (SS). Soil of the experimental site is predominantly Vertisol, deep, dark-colored Montmorillonitic clays (clay content is 40-65 %). It is characterized by low infiltration rate (2-3 mm/hr), low organic matter (1.4 %) and high pH (8.4). Most recent observations (1975-2004) show that the area is receiving mean annual precipitation of 600 mm. The seasonal rainfall (mm) measured at the site during the first (FS) and second (SS) seasons were 511.4 mm and 542.4 mm, respectively. They were less than the long-term average of Gedaref town (603 mm).

Treatments tested were, chisel plowing (CP), zero-tillage (ZT), and the conventional wide level disc (WLD) as a control. Randomized Complete Block Design with four replicates was used. The plot area was (15*20 m), with buffer zones left between plots and around the experiment area to facilitate crop management operations. The chisel plow was mounted on a 75 HP tractor. WLD treatment was done using a wide level disc harrow (WLD) connected to a 75 HP tractor, with a seed rate of 7.0 kg/fed as recommended by Agricultural Research Corporation 2004. Arfa'a Gadamak, (*Sorghum bicolor* L. Moench), a rainfed cultivar, was used as an indicator crop to study its performance under the treatments of conservation tillage techniques. In general, the crop cultural practices recommended by Agricultural Research Corporation (ARC, 2004) for the study area are followed. Sorghum seeds were planted in rows of 80 cm spacing across the main slope. 2 cm deep holes were manually punched; spaced 20 cm along the rows, and three seeds were placed per hole. About a month after sowing, plots were manually weeded and thinned to two plants per hole.

Rockstrom (2002) classified the effectiveness of tillage techniques on rain fed agriculture in semi-arid dry lands according to the following criteria:

- (i) Systems capability to prolong the duration of soil moisture availability in the soil.
- (ii) Systems characteristics to promote infiltration of rainwater into the soil.
- (iii) Systems ability to store surface and sub-surface runoff water for later use.

Consequently, these criteria are expressed quantitatively by adopting the following performance indicators: Soil moisture content (SMC), initial and final infiltration rate, precipitation use efficiency and yield and yield components of sorghum crop.

Water stored by each of the three treatments in the top 0.6 meter of soil depth (assumed to the depth of the root zone in this type of heavy soil) was determined in the form of depth (mm). The soil water stored (%) in each 0.2 m incremental depth down to 0.6 m was determined gravimetrically. It was then converted to water depth (mm) by multiplying by the specific bulk density values. Bulk density was measured by the core sampler method as described by Black (1965). Measurements of soil moisture content was done at three periods viz. at early season (P1), mid season (P2) and late season (P3) during both growing seasons.

Infiltration rate for each treatment was measured using double ring infiltrometer method and each test is replicated for four times and each run was made for a period of 240 minutes (Michael 1978). Infiltration measurements were taken at the end of the growing season.

Plant density, numbers of plants per meter square, was calculated using a 0.5 meter quadrant thrown randomly over the growing plants three times per plot. For days to 50% flowering, direct counting of flowering heads was made using the one-half meter quadrant. Three samples were taken randomly from each plot. The percentage of flowering plants was taken using the following relation:

% flowering plants = [Number of flowering plants/Total number of plants] *100

For plant height, five samples from each plot were randomly selected for plant height measurement at two times viz. early and late season, using a 2 m long measuring rod. The stem diameter measurement was made by randomly selecting five samples from each plot and the stem diameter was measured at two times viz. early and late season, using a vernier. A 0.5 meter quadrant was thrown randomly over the growing plants in each plot at the end of the growing season; the plants were cut, tied in bundles and left to dry for 10 days under the sun and then weighed to give the air-dry dry matter yield. Their heads were cut and the grains were threshed and weighed, and yield per square meter was recorded to have grain yield. Analysis of variance appropriate for complete randomized block design was applied by adopting IRRISTAT software (IRRISTAT, 2005).

Result and Discussion

Effect on oil moisture content (SMC):

Soil moisture content (SMC) of the soil 60 cm profile was measured at three periods, i.e. early season (P1), mid season (P2) and late season (P3). Table (1) shows the effects of the treatments on SMC at P1, P2 and P3. The apparent higher SMC in the second season (SS) was only due to rainfall better distribution through the growing season and higher quantity. In both growing seasons and at all measurement periods, the results obtained showed significant difference ($P>0.05$) in SMC between conservation tillage treatments and the WLD. The Zero-tillage treatment (ZT) recorded the lowest SMC values in both seasons at P1, but there was no significant difference ($P>0.05$) between ZT and WLD at any measurement period. This can attributed to the presence of deep cracks that take water deeper in the soil profile than the 60 cm depth. This is in contrast with Fabrizzi *et al.*, (2005) findings. WLD treatment recorded the lowest SMC values in both seasons at P2 and P3, while CP treatment recorded the highest values. This may be possibly be due to the increase in infiltration rate as the action of the chisel plow in breaking compacted soil deeper than WLD.

Table 1: Soil moisture content (mm/60 cm) as affected by soil and water conservation treatments.

Treatments	Period of measurements		
	Early Season (P1)	Mid season (P2)	Late season (P3)
First season			
WLD	201.946 ^{ab}	189.901 ^a	171.427 ^a
CP	221.422 ^b	210.405 ^b	189.675 ^b
ZT	188.269 ^a	193.910 ^a	175.558 ^a
LSD _{0.05}	28.7489	15.8818	12.0083
Second season			
WLD	281.177 ^{ab}	179.207 ^a	163.610 ^a
CP	296.479 ^b	219.550 ^b	212.834 ^b
ZT	258.996 ^a	196.70 ^{ab}	190.083 ^{ab}
LSD _{0.05}	29.3556	27.6531	35.2898

LSD_{0.05} = least significant difference at 5% level.

i- SMC in the First and Second Seasons at P₁:

In FS and SS there is significant difference ($P>0.05$) in SMC between CP and WLD and CP and ZT during the first season (FS) at the three periods. ZT decreased SMC in the root zone than WLD during the two seasons, but with no significant difference. These results are shown in table (1). The result was in agreement with Mohamed (2009) and Ibrahim (2008). It may be attributed to the fact that conservation tillage techniques are more beneficial later in the season and during later seasons as found by Fabrizzi *et al.*, (2005). The higher soil moisture content under WLD than ZT can be attributed to the effect of tillage by increasing soil surface

roughness, which may increase temporary surface water storage, and breaking soil crusts, which may facilitate infiltration of water that would be lost as surface runoff and the rapid entry of rainfall water through heavy (massive) and deep cracks in ZT treatments leads to low soil moisture content in the root zone.

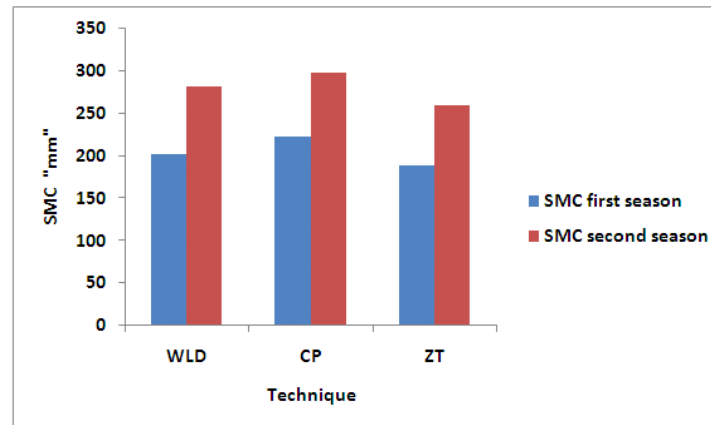


Fig. 1: Soil moisture content at early season (P_1) during first and second seasons.

ii- SMC in the First and Second Seasons at P_2 :

As can be seen in table (1) and figure (1), there is significant difference ($P>0.05$) in SMC between CP and WLD in the FS and SS, which may be attributed to the tillage depth in the CP, and the tendency to form surface crust in the WLD. There is a significant difference ($P>0.05$) in SMC is between CP and ZT in the FS only, which may be due to the relative dryness of this season and the increase in number and duration of the soil cracks. WLD treatment recorded the lowest SMC values in FS and SS. At this critical period of crop growth (flowering/yield formation), rainfall amounts were quite reasonable in both growing season (FS and SS), but WLD failed to store enough water in the root zone. This may be attributed to the excessive weed infestation in WLD treatment, which leads abstraction of more water from the root zone (unproductive use of water). The differences between WLD and ZT were not significant. This is in agreement with Mohamed (2009) and Ibrahim (2008).

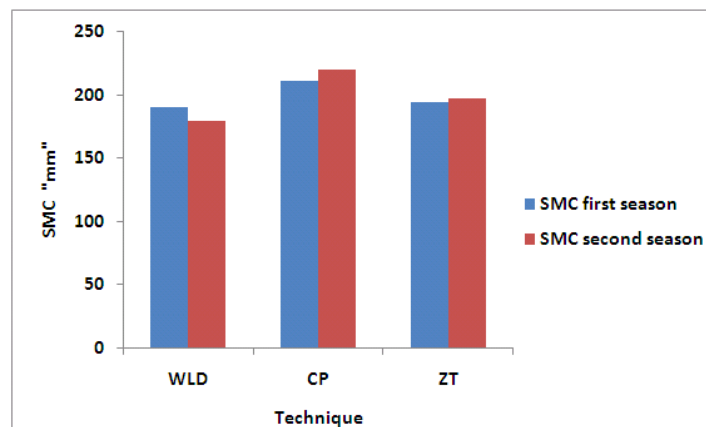


Fig. 2: Soil moisture content at early season (P_2) during first and second seasons.

iii- SMC in the First and Second Seasons at P_3 :

As table (1) and figure (3) shows there is significant difference ($P>0.05$) in SMC between CP and WLD in the FS and SS. this may be attributed to the tillage depth in the CP and the tendency to form surface crust in the WLD. Significant difference ($P>0.05$) in SMC was between CP and ZT during the FS only. This may be due to the relative dryness of this season and the increase in number and duration of the soil cracks. During the SS CP treatment recorded higher value than ZT. WLD treatment recorded the lowest SMC values in FS and SS. At this critical period of crop growth (flowering and yield formation), rainfall amounts were quite reasonable in both growing seasons (FS and SS), but WLD failed to store enough moisture in the root zone. Lowest SMC under

WLD can be attributed to the formation of soil surface crust, resulting mainly from soil dispersion, re-orientation of soil particles due to raindrop impact and the existing of the underneath hardpan, which may reduce soil infiltration through the soil. This result is in agreement with Mohamed (2009) and Ibrahim (2008).

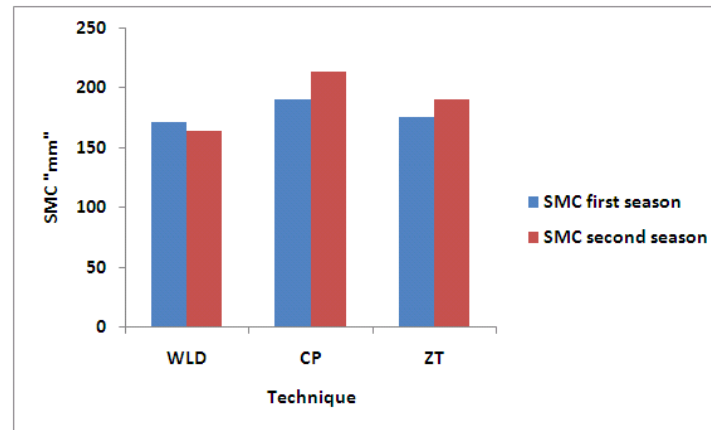


Fig. 3: Soil moisture content at early season (P_3) during first and second seasons.

Infiltration rate:

i- Initial infiltration rate:

Table (2) shows the means of the treatments in initial infiltration rate (during 5 minutes from the beginning). There is no significant difference between treatments in the FS. As can be seen that this parameter was greater in the chisel plow (CP) followed by wide level disc (WLD), and zero tillage (ZT), respectively. This is in agreement with Mohamed (2009) who investigated cumulative infiltration between ZT and WLD. It is in contrast with McHugh et al. (2007). The result can be attributed to the fact that WLD only stir soil surface while in ZT there is no soil movement and thus infiltration in ZT is less than that of WLD. Likewise the high initial infiltration obtained with CP is due to creation of pores although soil profile.

Table 2: Average initial infiltration rate (after 5 minutes) for conservation tillage treatments.

Treatments	Initial Infiltration rate (FS)	Initial Infiltration rate (SS)
WLD	0.185000 ^a	0.245000 ^{ab}
CP	0.205000 ^a	0.300000 ^b
ZT	0.165000 ^a	0.090000 ^a
LSD _{0.05}	0.055	0.118

LSD_{0.05} = least significant difference at 5% level.

In the second season (SS) there is significant difference between chisel plow (CP) and zero tillage (ZT) treatments only, which is in agreement with Mohamed (2009) who found no significant differences in cumulative infiltration between ZT and WLD. This may be due to soil nature for it swells in wetting and there by close soil pores and impede infiltration.

ii- Final infiltration rate:

Less time to reach final water intake rate reflect fast water movement into soil body due to creation of inter-spaces by tillage technique, this is shown in fig. (4), which show that chisel plow gave less time and soil attained saturated status faster. It is followed by zero-tillage which is followed by wide level disc.

Precipitation use efficiency (PUE):

Treatments means of precipitation use efficiency (PUE) is shown in table (3). The table reveals that there is significant difference between treatments ($p > 0.05$) in the two seasons. The significant difference in the FS was between ZT and WLD, while in the SS was between WLD and CP. This may be attributed to the difference in rainfall amount between the two seasons. This result is in agreement with Mohamed (2009) who found no significant differences in PUE values due to seasonal variations in a similar area.

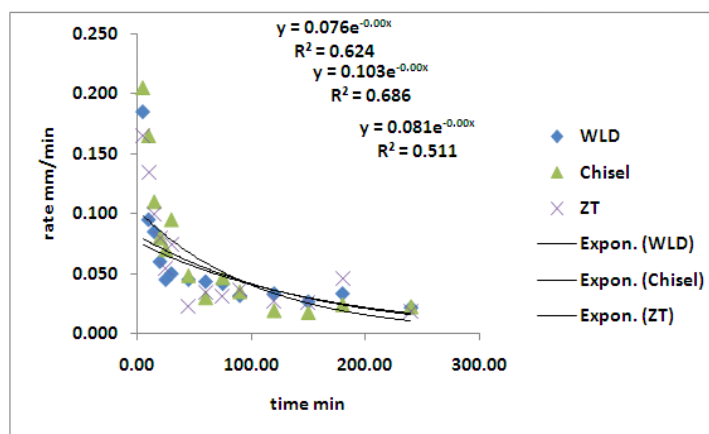


Fig. 4: Infiltration rate of the different techniques.

Table 3: Average precipitation use efficiency (PUE) for conservation tillage treatments.

Treatments	PUE (FS)	PUE (SS)
WLD	2.48114 ^{ab}	2.54915 ^b
CP	2.30190 ^a	2.21748 ^a
ZT	2.54874 ^b	2.49451 ^{ab}
LSD _{0.05}	0.186	0.314

LSD_{0.05} = least significant difference at 5% level.

Yield and Yield Components of Sorghum Crop (sorghum bicolor L.):

The effect of conservation tillage techniques on yield and yield components of sorghum crop were investigated during the first (FS) (2006/07) and second (SS) (2007/08) seasons. Parameters studied included stem diameter (SD) (cm), plant height (PH) (cm), days to 50% flowering (50%F) (days), plant density (PD) (plant/m²), grain yield (GY) (kg/ha), and dry matter (DM) (kg/ha). Table (4) depicts the means of the effects of the treatments on these parameters. Obtained results of these parameters showed no significant difference between treatments during the FS except for stem diameter at early season, grain and dry matter yield. Also there is no significant difference between treatments during SS, except for stem diameter and plant height at early season, days to 50% flowering, and grain yield. ZT treatment recorded the lowest values during the FS, but during SS it recorded the lowest values for both stem diameter, plant height at early season, and days to 50% flowering. This result emphasizes the late effect of ZT treatment. It is in agreement with Mohamed (2009) and in contrast with Ibrahim (2008) findings.

Table 4: Yield and yield components as affected by soil water conservation treatments.

Treatments	Stem diameter Early (cm)	Stem diameter late (cm)	Plant height early (cm)	Plant height Late (cm)	Days to 50% flower	Plant density (plant/m ²)	Yield (g/m ²)	Dry matter yield (g/m ²)
First season								
WLD	0.34 ^a	1.76 ^a	3.38 ^a	88.35 ^a	52.50 ^a	25.00 ^a	206.25 ^a	1057.5 ^{ab}
CP	0.38 ^b	1.84 ^a	4.87 ^a	91.70 ^a	52.25 ^a	28.00 ^a	222.75 ^b	1202.5 ^b
ZT	0.33 ^a	1.78 ^a	3.31 ^a	87.00 ^a	52.50 ^a	24.00 ^a	200.75 ^a	852.5 ^a
LSD _{0.05}	0.03	0.25	1.66	19.69	2.69	10.76	16.917	316.57
Second season								
WLD	0.39 ^a	1.82 ^a	4.08 ^b	88.45 ^a	54.0 ^a	28.0 ^a	213.2 ^a	1070.00 ^a
CP	0.34 ^b	1.77 ^a	3.80 ^{ab}	90.58 ^a	53.2 ^a	36.0 ^a	245.0 ^b	1235.00 ^a
ZT	0.34 ^b	1.84 ^a	3.26 ^a	99.45 ^a	44.5 ^b	33.0 ^a	220.5 ^{ab}	1157.50 ^a
LSD _{0.05}	0.12	0.21	0.76	12.36	1.85	9.15	28.87	267.03

LSD_{0.05} = least significant difference at 5% level.

i- Stem Diameter (SD) and Plant Height (PH):

As can be seen from table (2) treatments showed significant difference ($P > 0.05$) in SD during FS and SS at the early season. The difference is significant between each of CP and ZT and WLD treatments, but not significant between ZT and WLD, and ZT have the lowest value. Also they showed no significant difference in SD during FS and SS at the late season measurement, with ZT having the highest value during SS and CP during the FS. Figures (5) and (6) depict the values obtained by the treatment.

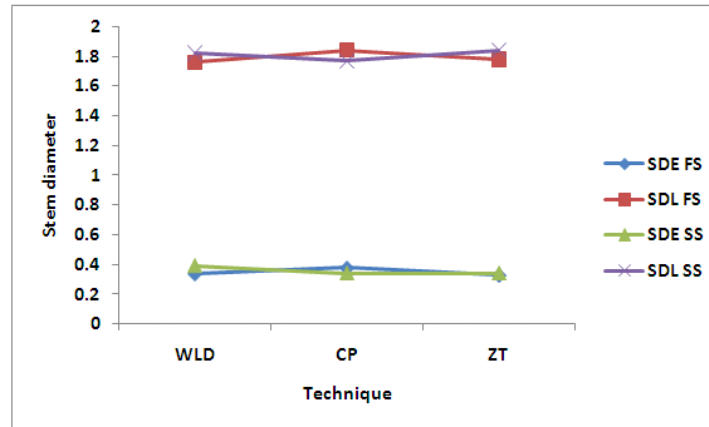


Fig. 5: Effect of treatments on the plant height in the two seasons (first (FS) and second (SS)) and at the two periods.

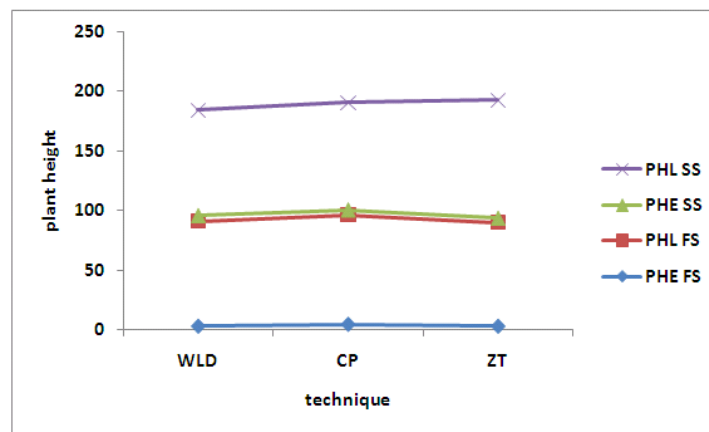


Fig. 6: Effect of treatments on the plant height in the two seasons (first (FS) and second (SS)) and at the two periods.

ii- Days to 50% Flowering (50% F):

As can be seen from table (2), treatments have no significant difference concerning 50% flowering during FS. However, during the SS there is significant difference ($P > 0.05$) between ZT and the other treatments with the ZT having the lowest value. CP treatment recorded the highest number of days to 50% flowering. This may be due to higher moisture content that encourages vegetative growth and delayed flowering (Fig. 7).

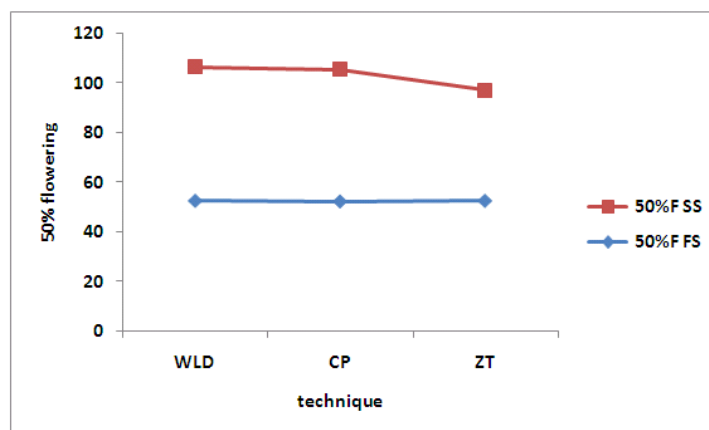


Fig. 7: Effect of treatments on fifty percent flowering in the two seasons (first (FS) and second (SS)).

iii- Plant Density (PD):

As can be seen from table (2), no significant difference between treatments noticed during the two seasons (FS and SS). In FS and SS, the lowest value of PD was recorded under ZT and WLD, 24 plant/m² and 28 plant/m², respectively. This may be attributed to the low amount of moisture that is stored in the root zone under ZT and WLD, and the formation of hard soil surface crust as well as the inaccurate seeding depth under the WLD treatment. Low soil moisture content, formation of soil crusts and inaccurate seeding depth may adversely affect seeds germination and seedlings emergence which may reduce PD. This is in agreement with the findings of Hemmat (1996), who reported that soil compaction has an adverse effect on plant properties such as seedling emergence, root growth and crop yield. They recommended sub-soiling and deep plowing to alleviate soil compaction. Soil water status influences seed germination and seedling emergence through its effect on the rate of water imbibition, which is governed by hydraulic conductivity of soil (Collins-George and Sands, 1959), the degree of seed-soil contact (Hadas and Russo, 1974) and differences in osmotic and matric potential between bulk soil and the soil in close proximity to the seed (Collis-George and Sands, 1959 and Rose and Hegarty, 1979). The highest PD value during the two seasons was recorded under CP. This result can be attributed to the advantages provided by the chisel plow, i.e. breaking soil crust, improving soil tilth (Unger, 1984), enhancing infiltration and better soil structure due the presence of organic matter, which may improve the germination and emergence conditions and thus increase PD (Fig. 8).

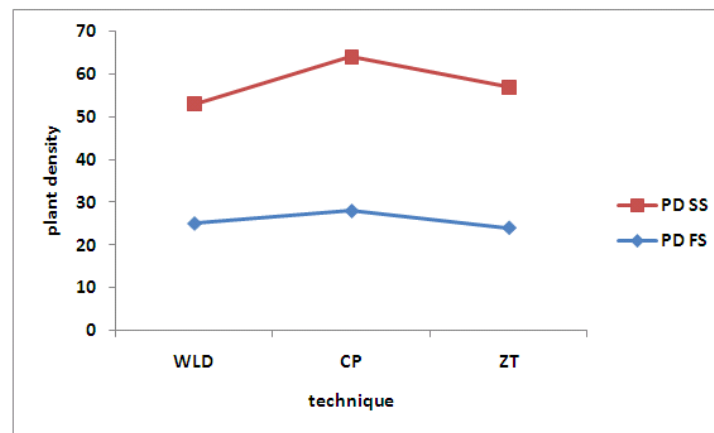


Fig. 8: Effect of treatments on plant density in the two seasons (first (FS) and second (SS)).

iv- Grain Yield (GY) and Dry Matter (DM) in the FS and SS:

Table (2) indicated that the treatments have significant differences ($P > 0.05$) in grain yield (GY) during FS and SS. The difference is significant between CP and the other two treatments (WLD and ZT). The lowest GY value was recorded under ZT and WLD in the FS and SS respectively. This means that ZT gave better results during SS, which emphasizes the late effect of the ZT as recorded by Fabrizzi *et al.*, (2005).

Treatments have significant difference ($P > 0.05$) in the dry matter (DM) during FS between CP and ZT only. No significant difference during SS. The lowest DM values in the FS were recorded by ZT followed by WLD. During the SS lowest DM values were recorded by WLD followed by ZT emphasizing the late better effect of the ZT. The low dry matter yield (DM) obtained under ZT and WLD treatment was mainly due to the increased weed infestation, low plant density, poor soil-seed contact, associated with the use of the WLD for seeding, and soil compaction, also due to the increase in soil moisture content by the CP treatment. The result obtained under WLD is in line with the findings of Hemmat (1996), Fabrizzi *et al.* (2005), Lal, 1998; Pala *et al.*, 2000 and Astatke *et al.* 2003 (Fig. 9).

An important challenge for modern agronomy is to forecast crop yield before harvesting and to estimate soil-crop characteristics during growing season by means of crop growth models. However, an important limitation, which prevents to reach that aim, is that the crop growth models are driven by a large amount of input parameters (crop, soil and weather data), which are not always available during the growing season and in the space. Whisler *et al.*, (1986) stated that empirical models describe relationships between variables without referring to any underlying biological or physical structure that may exist between the variables. A big drawback to statistical models is that very often they will be location-specific and, while given good results in average or near average conditions, they may not reflect the real conditions in extreme weather situations. To predict grain yield depending on soil moisture content empirically actual yield was curve-fitted against moisture content at

each period (P1, P2 and P3), and the constants were taken for each treatment. These constants were used to estimate yield by deriving a relationship for each treatment (table 5).

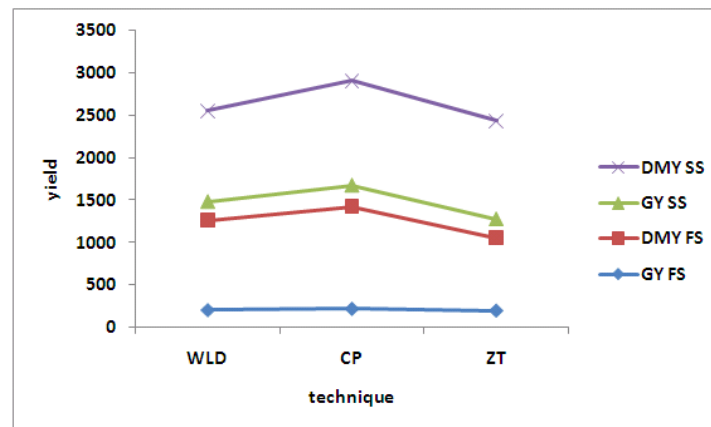


Fig. 9: Effect of treatments on grain and dry matter yield in the two seasons (first (FS) and second (SS)).

Table 5: Coefficients of yield for each treatment as a function of soil moisture in various plant growth periods.

Treatment yield	_Co	_Early MCP1	_Mid MCP2	_Last MCP3	R ²
WLD	1301.997	-3.77581	0.286552	-1.6314	
CP	835.4044	-1.34518	0.282135	-1.48182	
ZT	1.282454	0.0469	0.282135	0.50025	

Where: _Co is the technique constant, _Early is the coefficient of early season moisture content, _Mid is the coefficient of mid season moisture content, _Late is the coefficient of late season moisture content, MCP1 is the early season soil moisture content (mm), MCP2 is the mid season soil moisture content (mm) and MCP3 is the late season soil moisture content (mm).

Conclusions:

The study revealed the potential advantages of conservation tillage for semi-arid zones and in particular for Northern Gedaref, Sudan. In reference to the rationale of adopting tillage techniques and depending on the results of this work the following conclusions can be summarized as follows:

1. Conservation tillage techniques improved soil moisture stored within the root zone as compared to the conventional harrowing using the wide level disc, resulting in higher dry matter and grain yield of sorghum.
- 2- The zero-tillage technique was best than conventional tillage, but becomes clearer late in the season and in coming seasons, this effect may be due the absence of the plant residues that they could be removed for other uses.
- 3- The zero-tillage and wide level disc treatments were found not conservative to the effect on initial infiltration rate. For time to reach final intake rate chisel plow is the one that takes little time.
- 4- The zero-tillage treatment has a small effect on precipitation use efficiency.

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