ORIGINAL ARTICLES

Effect of Planting Geometry on Soil Moisture Content, Yield and Yield Component of Sorghum (*Sorghum bicolor* L. Moench).

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ABSTRACT

Grain sorghum is the main staple food for human and animal consumption in the Sudan. It is mainly cultivated in the rain fed mechanized farming system in Gadaref area and southern Blue Nile areas. Stand establishment is often a concern with grain sorghum producers. Adverse weather and soil conditions may prevent grain sorghum growers from achieving an evenly spaced, optimum plant density. Grain sorghum yield response to row spacing was variable and dependent upon environment. This study investigates the effect of different planting geometry on soil moisture content and sorghum yield. Treatments tested were, planting on top of tied ridges (PTR), planting in the bottom of ridges (PBR), and flat broadcasting (FLAT) and corrugations using the conventional wide level disc (WLD). The study reveals that using ridges is better than the others and even planting on flat is better than the conventional method used in the mechanized rainfed sector with respect to soil moisture and yield and yield components.

Key words: planting geometry, soil moisture, grain and dry matter yield, yield component, sorghum.

Introduction

In 2006, the World Food Summit defined food security as: "All people at all times have access to sufficient, safe and nutritious food to maintain a healthy and active life". The lack of food security has an impact on civil and national security. Therefore long-term solutions are required to address it. Broadly, the concept of food security is built on three pillars:
i) Food availability: sufficient quantities of food are available to people on a consistent basis.
ii) Food access: people have sufficient resources to obtain appropriate foods for a nutritious diet.
iii) Food utilization: people have sufficient knowledge of nutrition and care practices and access to adequate water and sanitation to derive sustenance food.

One effective tool for development of rural areas is to direct available water resource to produce more food per drop of water. For arid dry areas it is essential to conserve available resources if it is not possible to develop new sources. The road way is to adopt improved integrated water resources by defining the most feasible water harvesting techniques so as to maximize benefit from rain fall coming directly into the soil or as part of runoff water in small wadis and Khors. Water productivity in rain-fed agriculture will have to increase dramatically over the next decades if food production is to keep pace with human population growth (Rockström *et al*., 2002). Rain-fed agriculture is practiced on approximately 95% of agricultural land, with only 5% under irrigation (Rockström *et al*., 2002). This shows that rain-fed agriculture will remain the dominant source of food production for the foreseeable future in sub-Saharan Africa.

In many parts of the water-scarce countries in Africa and in particular the rainfed Sorghum producing areas, yields from rainfed agriculture are low, oscillating around 1 t.ha^{-1} (Rockström, 2001). However, many researchers suggest that the low productivity in rain-fed agriculture is more due to sub-optimal performance related to management aspects than to low physical potential. A reduction in runoff will result from practices that successfully increase the infiltration capacity of the soil, increase the contact time, and/or reduce surface sealing. It is commonly accepted that covering the soil with mulch, for example, with a crop residue, will achieve these goals (Unger, 1990) and will also reduce evaporation from the soil surface.

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It is also reported that the use of mulch in the basins reduced evaporation significantly, contributing to the increase in yield, on average 30 to 50%, compared to production under conventional tillage (Hensley *et al*., 2000; Botha *et al*., 2003). Based on this status this study shall be directed to develop innovative applied research to generate adaptable technology in rain water management for small holders. The area chosen for study is the mechanized rain fed agriculture of the Gedaref state, Eastern Sudan, constitutes a great portion of the cultivated area in the country. The annual cultivated area fluctuates between 210 to 252 thousand hectares. Two agricultural systems are prevailing, traditional and mechanized farms. According to the amount of rainfall, the region is divided into three sub regions of high, medium and low rains; with total rainfall ranging between 900-700, 700-500 and 500-300 mm from South to North, respectively (MFC, 2003). The region is dominated by non-governmental schemes which are characterized by low inputs, poor cultural practices and low crop yields (Ahmed, 1995). Sorghum represents the most widely sown crop. Generally, farmers begin to cultivate their fields when a cumulative rainfall reaches about 100-125 mm. They 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. Moreover, rain-water is the main limiting factor for crop production in the region, especially in the Northern region. Therefore, it is important to manage the soil for high moisture retention and storage of rain-water for crop use.

The list of candidate alternative *in-situ* water harvesting techniques may includes use of different agricultural machinery to modify soil surface geometry (planting in the bottom of the furrow, on top of the tied ridge, on flat and on corrugations) to suit cropping requirement, to improve soil infiltration rate in combination with direct rain harvesting techniques. The rationale of using these techniques is the reduction of evaporation from soil and water surfaces through appropriate land management. These options are expected to reduce impact of drought on food crops by adoption of appropriate techniques for conservation of soil moisture in warm and dry areas. To insure food availability water centered development is a key strategy.

The vast majority of the population in Rain fed Mechanized Farming areas is poor. From review of factors affecting productivity of crop production in rainfed areas it is evident that the main constraint is unreliability and inadequacy of rainfall water. Therefore, it is aimed that this research is a vital step to innovate the relevant techniques for remedy.

Overall objectives:

Enhancement of food security and reduction of poverty through development of innovative applied research to generate adaptable technology in soil water management for small holders in rain fed areas.

Specific objectives:

Selection of adaptable water management techniques to manage soil and rain water to increase food productivity in warm and dry areas; to reduce impact of drought on food crops by adoption of appropriate techniques for management of soil moisture in rainfed farming; to improve the livelihood of the people living in that area, by studying the effect of different planting geometry such as planting on top of the ridges, in the bottom of the furrow, on flat and broadcasting on corrugations (conventional planting method) on soil moisture content, infiltration rate, precipitation use efficiency and yield and yield components of sorghum crop under rainfed conditions.

Past research on establishment and formation of plant beds:

Stand establishment is often a concern with grain sorghum producers. Adverse weather and soil conditions may prevent grain sorghum (*Sorghum bicolor* L. Moench) growers from achieving an evenly spaced, optimum plant density. In these situations, growers must decide whether to replant or manage a grain sorghum crop with uneven and/or lower stands. Research indicated that sorghum grain yield response to row spacing was variable and dependent upon environment (Conley *et al*., 2005). In a uniform stand, grain sorghum yield was not decreased until plant densities were reduced to less than 60,000 plants per acre. However, in most field settings grain sorghum plant densities are rarely uniform. As given by Ottman and Olsen (2009) Grain sorghum can be planted in row spacing ranging from 15 to 100 cm apart or in twin rows in a variety of configurations. Grain sorghum will generally yield more when planted in 50 or 75 cm rows compared to 100 cm rows or in twin rows spaced 30-35 cm apart on 95-100 cm beds. Grain sorghum can be planted on beds or on flat ground. The optimum seeding rate for grain sorghum is about 10 pounds of seed per acre. The goal is to achieve a plant density of 100,000 plants per acre. Seeding rate can be increased by 20% if row spacing is 75 cm or less, with a non-tillering or short season hybrid or if planting in twin rows. On a sandy clay loam soil, tied furrows increased sorghum yield by 62 % in 4 out of 5 seasons compared to the farmer's practice of sowing on the flat

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(Nyamudeza, 1993). In central Queensland, eleven trials conducted between 2001 and 2004 showed yield benefits from wide-rows when sorghum yields below 3 t/ha. Out of 11 trials, 5 showed a gain, 3 trials showed a penalty from using wide rows and 3 trials showed no difference (Collins *et al.* 2006).

Benites (2000) reported that the technique of ridging before planting consists of plowing the area and then opening up furrows at 0.75 m row spacing. This system, owing to the ridge defining the line of planting, allows better use of the rainwater and also optimizes the weeding, pest and disease control operations. Its use is however, limited by the presence of stumps, stones or slopes steeper than 5 percent. Another solution is making narrow ridges and planting on top of these. Planting pattern influences radiation interception and utilization of moisture from soil (Rehman 2002). It is well documented that line sowing in appropriate rows is the best strategy (Ansari et. al 2000) and 30 cm apart single row planting geometry gave significantly higher grain yield (Tayyab 2000).

Malik *et al*. (2006) found that planting patterns of *Vigna radiata* L. had non-significant effect on number of plants per square meter. Different planting patterns had also significant effect on plant height. Maximum plant height was attained by P1 (30 cm apart flat sowing). P3 (20 cm apart on 40 cm wide beds) attained minimum plant height that was statistically at par with P2. Younas (1993) also observed that plant height was significantly affected by different planting patterns. Effect of sowing dates and planting patterns on grain yield was significant (Tayyab 2000).

Under rainfed agriculture conditions, high water storage in the soil profile is an important factor affecting crop production (Elramlawi *et al.,* 2009). FAO (1995) pointed out that the strategies for increasing water infiltration into the soil are based either on increasing the infiltration capacity or increasing the time for rainwater to infiltrate into the soil. Both situations can be attained through application of structural and/or agronomic conservation measures (Mohamed, 2000). Formation of soil surface can reduce runoff velocity and impound water and thus increase water availability within crop root zone.

As given by Mohammed (2010) the geometry of the furrow determines the surface area exposed for infiltration. Wider furrows with deep depth allow more contact area than narrow ones. Increasing furrow shoulder means increasing water collecting area while furrow bottom may be regarded as utilization area when seeds are planted in furrow beds. To increase volume of water stored inside furrow bottom furrows are divided into multi-basins by small dykes or ties. Ridging is done by constructing small earth banks parallel to the contours of a slope. The water accumulates above the ridges and is thus allowed to infiltrate into the soil. An alternative to ridges is the construction of small earth mounds. In ridging system planting configuration is made through placement of seeds or tubers either near the top of the ridge (to avoid water logging) or towards the bottom of the basin where rainfall and/or soil moisture are limited. Tied-ridging is one such technique that is being promoted to conserve rainwater in farmer's fields. Tied-ridging is known in other parts of the world as boxed ridges, furrow dikes, furrow damming, basin listing, basin tillage and micro-basin tillage (Jones and Stewart, 1990). Tied-ridging is not a new technology within Malawi and the rest of the SADC. It has been promoted in the 1960s and 1970s for surface runoff-induced erosion control since tied-ridges retain surface runoff within the field. Given erratic rainfall, the aim is no longer just erosion control but also rainwater conservation. The aim in such cases is to conserve the limited rainwater and store it in the maize root zone for use during dry spell periods. Past and recent research in Botswana (Carter and Miller, 1991), Zimbabwe (Piha, 1993; Vogel, 1993), Burkina Faso (Hulugalle and Matlon, 1990) and USA (Krishna, 1989) have revealed that tied-ridging is effective in reducing surface runoff and increasing soil water storage. Tied-ridging often leads to little or no surface runoff during normal storms. In severe storms, however, other research in Africa as reviewed by El-Swaify et al. (1985) has revealed that tied-ridging can lead to ridge overtopping, ridge failure, water logging and total loss of the crop. Many studies on tied-ridging have focused on the relationship between tied-ridging and crop yield. The yield has been found to vary depending on the amount and distribution of rainfall, soil type and the crop grown. Few studies have focused on the effect of tied-ridging on soil water status under different soils, rainfall regimes and crops. Research on the effect of tied-ridging on all water balance components is largely nonexistent in the literature. This is partly due to the fact that to evaluate soil water status, extensive soil moisture and surface runoff data need to be measured.

Water use efficiency is generally defined as the non-dimensional ratio of output, for example yield, over input, depth of water used. Water use efficiency (WUE) is a commonly used term but there is no common definition has been adopted (UNESCO, 2002). Water use efficiency is customary used as evaluation indicator of performance of water management technique. All types of water use rainfall, (evapo-)transpired water, irrigation water, etc. were being evaluated; and the types of output vary according to the objectives of the evaluation process. Water use efficiency (WUE) therefore refer to crop yield per unit rainfall, total biomass per unit of water or mass of hydrocarbons stored per unit water transpired (Duivenbooden *et al.,* 2000). For the case of rainfed agriculture WUE had been replaced with more specific definitions such as precipitation use efficiency (PUE), and the calculation procedures in particular refers to crop yield per unit rainfall. Hemmat and Eskandari, (2006) reported that, PUE is significantly influenced by tillage systems. 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).

Materials and Methods

An experiment was conducted at the Faculty of Agricultural and Environmental Sciences, University of Gedaref, Demonstration Farm at Twawa area (Longitude 35.24° E, Latitude 14.02° N and altitude of about 600 m AMSL) for two consecutive seasons in 2006/07 (FS) and 2007/08 (SS). Soil of the experimental site is of Vertisol type, 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). Records show that the area is receiving means annual precipitation of 600 mm. 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.

Treatments tested were, planting on top of tied ridges (PTR), planting in the bottom of ridges (PBR), on flat in rows (FLAT) and broadcasting on corrugations using the conventional wide level disc (WLD). 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. Ridges, in both PTR and PBR treatments, of 0.8 m spacing were constructed using a ridger implement mounted on a 75 hp tractor. Cross earth ties in PTR, 8-12 cm in height, were manually constructed with hand hoes at 1.5 m apart. Sowing in PTR was done on top of the ridge, in PBR was done in the furrow bottom and the flat was done in definite rows on an untreated soil surface. Holes 2 cm deep were manually punched; spaced 20 cm along the rows, and three seeds were placed per hole. 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.

Water stored in the top 0.6 meter soil depth (assumed to be the depth of the root zone in this type of heavy soil) by each of the four treatments was determined in the form of depth (mm). 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. Arfa′a Gadamak, (*Sorghum bicolor* L. Moench), a local cultivar, was used as an indicator crop. Its performance under different planting geometry was studied. About a month after sowing, plots were manually weeded and thinned to 2 plants per hole.

Infiltration rate for each treatment was measured at the end of the growing season using double ring infiltrometer method, one test was done for each plot, and each run was made for a period of 240 minutes (Michael 1978).

The data of infiltration was related using logrithmatic least-square method to determine initial and final intake rate for each treatment (ElRamlawi,).

For 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 using the one-half meter quadrant was used. Three samples were taken randomly from each plot and the number of days required for 50% of flowering plants was recorded. For plant height, five samples from each plot were randomly selected for height measurement two times viz. early and late season, using a 2 m long measuring rod. For plant diameter, five samples from each plot were randomly selected and the stem diameter was measured two times viz. early and late season, using a vernier at the middle of the stem length. For dry matter, 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. For grain yield, a one-half meter quadrant was thrown randomly over the growing plants in each plot at the end of the growing season; the heads were cut and the grains were threshed and weighed and yield per square meter was recorded. Analysis of variance for Complete Randomized Block Design was applied by adopting IRRISTAT software (IRRISTAT, 2005).

Result and Discussion

Total amounts of rainfall (mm) measured during the two rainy seasons were 511.4 mm and 542.4 mm for the first (FS) and second (SS) seasons, respectively. They were less than the long-term average of Gedaref area (600 mm).

Soil moisture content (SMC):

Soil moisture content (SMC) of the soil in 60 cm profile was measured at three periods, i.e. early season (P1), mid season (P2) and late season (P3). The means of the treatments for SMC at P_1, P_2 and P_3 during the first

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(2006/2007) and second (2007/2008) seasons are shown in table (4.1). In both growing seasons at all measurement periods, the results obtained showed significant difference (P>0.05) in SMC between treatments. Corrugation planting (WLD) treatment recorded the lowest SMC values in both seasons at P2 and P3, while PTR treatment recorded the highest values. No significant difference between PTR and PBR during the two seasons. Figures (1) and (2) show moisture conserved by the different treatments at different periods, namely early, mid and late season, during the first (FS) and second (SS) seasons, respectively. These results are in agreement with Ibrahim (2008), Mohamed (2009), Jones and Stewart (1990), Gebrekidan (2003).

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

Treatments	Period of measurements		
	Early Season (P$_1$)	Mid season (P$_2$)	Late season (P$_3$)
First season			
WLD	201.95[ab]	189.90[a]	171.43[a]
PBR	219.06[b]	203.10[ab]	186.77[abc]
PTR	221.60[b]	215.02[b]	192.09[c]
FLAT	188.27[a]	193.910[a]	175.56[ab]
LSD $_{0.05}$	22.09	16.34	11.42
Second season			
WLD	281.18[a]	179.21[a]	163.61[a]
PBR	292.89[a]	212.75[b]	216.55[b]
PTR	292.74[a]	210.28[b]	208.10[b]
FLAT	258.10[b]	196.71[b]	190.08[ab]
LSD$_{0.05}$	27.33	16.60	35.82

LSD$_{0.05}$ = least significant difference at 5% level.

Fig. (1) shows that PTR conserve more than other techniques in all growth periods. Likewise fig. 4.2 both PTR and PBR retained the highest soil moisture content. This may be due to presence of the furrow which act as storage pond. This is more clear when we see that corrugation rank second to furrow treatments, while flat treatment store the least amount of soil moisture in all periods in the two seasons (fig. 1 and 2).
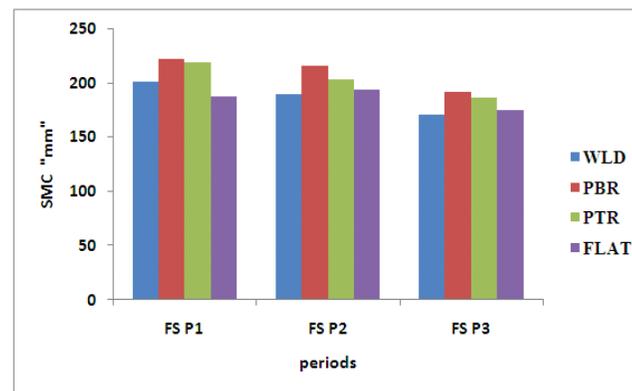

Fig. 1: Moisture content retained by different treatments at the three periods during FS.
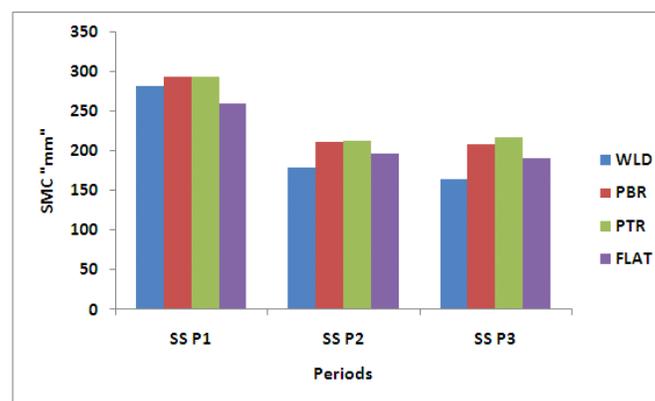

Fig. 2: Moisture content retained by different treatments at the three periods during SS.

Effect on infiltration rate:

i- initial infiltration rate: As depicted in table (2) there is significant difference between tide ridges and the other treatments in the first season (FS), but in the second season (SS) there is significant difference between FLAT and the other treatments. This may be attributed to the small effect of sealing caused by rains because of less rainfall in this season. This is in contrast with Mohamed (2009) who found no significant difference between the same treatments. It is in agreement with Chilimba (1999).

Table 2: Treatments means for initial infiltration rate in the two seasons.

Treatments	Initial infiltration rate (FS)	Initial infiltration rate (SS)
WLD	0.185[a]	0.245[a]
PBR	0.210[a]	0.245[a]
PTR	0.325[b]	0.290[a]
FLAT	0.165[a]	0.090[b]
$LSD_{0.05}$	0.095	0.148

$LSD_{0.05}$: least significant difference.

Final infiltration rate:

The less the time to reach basic infiltration rate, the better and easy is the pass of water through the soil. The treatments show variation in this characteristic. The time taken by each treatment was in the order WLD>FLAT=PTR >PBR. This shows that (WLD) treatment is the worst of them (Fig. 3).
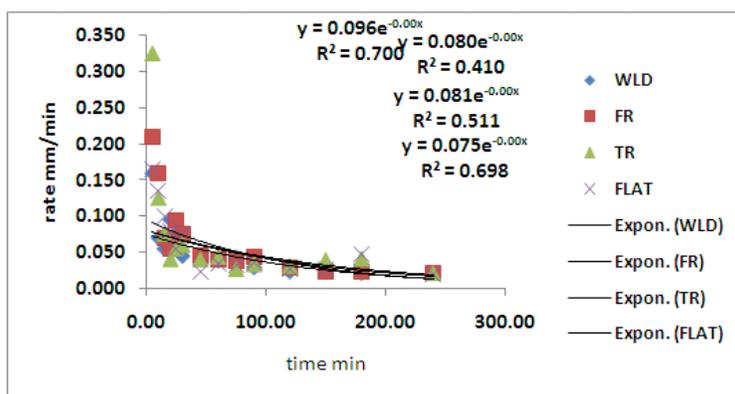

Fig. 3: Infiltration rate of the different planting methods.

Precipitation use efficiency (PUE):

Table (3) shows the result of PUE. There is significant difference (p>0.05) between treatments in the two seasons. Low PUE values recorded under both WLD and FLAT in the two seasons can be attributed to the slow and small water movement downward soil profile. High PUE obtained under PTR, and PBR can be attributed to high amounts of rain water stored in the root zone due to creation of more pore spaces. The result is in agreement with Li and Gong (2002) and Mohamed (2009).

Table 3: Treatments means for Precipitation use efficiency in the two seasons.

Treatments	PUE FS	PUE SS
WLD	0.393[a]	0.380[b]
PBR	0.395[a]	0.44[a]
PTR	0.422[b]	0.487[a]
FLAT	0.393[a]	0.407[b]
$LSD_{0.05}$	0.020	0.068

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

The effect of planting geometry on yield and yield components of sorghum crop were investigated during the first (FS) and second (SS) seasons, 2006/07 and 2007/08 respectively. Measured data included plant diameter, PD, (cm), plant height, PH, (cm), days to 50% flowering, 50%F (days), plant density, PD, (plant/m^2), grain yield, GY, (gm/ m^2), and dry matter, DM, (gm/ m^2). Table (4) depicts the mean effects of the treatments on these parameters. Obtained results of yield and yield components parameters showed no significant

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difference between treatments during the FS except for plant diameter at early season, plant density and grain yield. Also there is no significant difference between treatments during SS except for plant height at early season, plant density and grain yield. These results are in agreement with Ibrahim (2008), Mohamed (2009), Jones and Stewart (1990), Gebrekidan (2003) and Belschew and Abera (2010).

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

Treatments	stem diameter Early (cm) (SDE)	Stem diameter late (cm) (SDL)	Plant height early (cm) (PHE)	Plant height Late (cm) (PGL)	Days to 50% flower (D_{50})	Plant density (plant/m^2) (PD)	Yield (g/m^2) (GY)	Dry matter yield (g/m^2) (DMY)
First season								
WLD	0.34[ab]	1.76[a]	3.38[a]	88.35[a]	52.50[a]	25.00[a]	206.25[ab]	1057.50[a]
PBR	0.36[ab]	1.95[a]	3.69[a]	93.20[a]	51.50[a]	28.00[a]	214.00[b]	1227.50[a]
PTR	0.38[b]	1.87[a]	3.48[a]	93.10[a]	50.50[a]	33.00[b]	228.75[c]	1190.00[a]
FLAT	0.33[a]	1.78[a]	3.31[a]	87.00[a]	52.50[a]	24.00[a]	200.75[a]	852.50[a]
LSD$_{0.05}$	0.05	0.24	0.79	19.11	2.77	8.33	13.63	424.09
Second season								
WLD	0.39[a]	1.82[a]	4.08[ab]	88.45[a]	54.0[a]	28.0[a]	213.25[a]	1070.00[a]
PBR	0.37[a]	1.69[a]	5.22[b]	83.73[a]	53.25[a]	37.0[b]	239.00[ab]	1300.00[a]
PTR	0.33[a]	1.83[a]	3.44[a]	86.85[a]	54.50[a]	35.0[b]	264.00[b]	1282.50[a]
FLAT	0.34[a]	1.84[a]	3.26[a]	99.45[a]	44.50[b]	33.0[b]	220.50[ab]	1157.50[a]
LSD$_{0.05}$	0.10	0.28	0.94	20.35	3.52	4.30	30.14	486.38

LSD$_{0.05}$ = least significant difference at 5% level.

As given in table (5) 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 may be used to estimate yield after deriving a relationship for each treatment. Therefore grain yield that can be obtained from each treatment would be predicted using these relationships as follows:

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	
PBR	- 493.813	3.47977	0.81898	-1.70281	
PTR	10000000	- 43972	- 3966.95	10284.23	
FLAT	1.282454	0.0469	0.409731	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 planting on ridges, planting on flat and broadcasting and corrugations using the wide level disc in semi-arid zones and in particular in Northern Gedaref, Sudan. Depending on the results of this work the following conclusions can be summarized as follows:
1- Using ridges for planting improved soil moisture stored within the root zone as compared to the conventional flat broadcasting and on corrugation planting using the wide level disc, resulting in higher dry matter and grain yield of sorghum.
2- Also planting on ridges, in furrows resulted in better infiltration of water even at the end of the season, when infiltration rate was measured.
3- Using ridges and furrows for planting increases precipitation use efficiency above the broadcasting and the conventional method WLD.

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