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Effect of Water Harvesting Techniques and Chisel Plough Depth on Sorghum Production (*Sorghum bicolor* L.) Under Dryland Farming in Gadaref State, Sudan

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ABSTRACT

This study was conducted to evaluate the effect of water harvesting techniques and chisel plough depth on yield and yield components of sorghum (*Sorghum bicolor* L.) under the dryland farming of Gadaref State during three consecutive seasons (2010/09, 2011/10 and 2012/11). The experimental field was arranged in a split-plot design replicated three times each consisting of three main plots which were ploughed by chisel depths of 20 (D1), 25 (D2), and 30 cm (D3). Each main plot was divided into five subplots each with size of 3×6 m^2 to include five different treatments, which were randomly distributed. They were respectively used wide level disc (WLD) as conventional tillage practice, and two tied- ridging spaced at 1 m (TR1) and 2 m (TR2) and {two furrow-ridge with ratios of 1:1(RF1) and 2:1(RF2)}. The latter four treatments were considered as in- situ rain water harvesting techniques. Amounts of monthly rainfall (mm), measured within the three rainy seasons, and collected crop data were plant population(PP), plant height at flowering (PH), dry matter (DM), total grain yield (GY), water productivity (WP) and 1000 seeds weight (1000 SW). The result showed no significant ($p>0.05$) difference between interaction water harvesting techniques (WHT) and chisel depth, in three seasons on (PP), (PH),(GY), (DM) and (WP).except (GY), (DM) and (WP), in the third season (TS), the result showed that the highest grain yield 2356.70 kg/ha for sorghum was produced by TR2 under (D3) and lowest grain yield 1448.30kg/ha was produced by WLD under (D1), and the highest (DM) 1386.70 kg/ha for sorghum was produced by TR2 under (D3) and the lowest (DM) 801.00kg/ha was produced by WLD under (D1), and highest (WP) 0.67 (kg/m^3) for sorghum was produced by TR2 under (D3) and lowest (WP) 0.39(kg/ $m^3$was produced by WLD under (D1). There were significant ($p<0.05$) difference between interaction water harvesting techniques (WHT) and chisel depth, except in the first season (FS) on (1000 SW), result also showed that the highest (1000 SW) 32.90 and 27.0 (g) for sorghum was produced by TR2 in SS and TS respectively under (D3) the lowest (1000 SW) 20.90 and 19.10 (g) was produced by WLD in SS and TS respectively under (D1).The data suggested that use of simple *in-situ*

water harvesting techniques could be used successfully to meet the water demand of sorghum in the North of Gadaref State, which suffers from the intermittent and low rainfall.

INTRODUCTION

Rain water harvesting (RWH) is defined as the process of capturing and collecting rain water which could be conserved for direct use or for recharging the ground water (Ahmed and Naggar, 2003). Salih *et al.,* (2003) reported that water harvesting is simply the utilization of runoff water for different purposes. According to Evanari *et al.,* (1971) a growing awareness of the potential of water harvesting for improved crop production arose in the 1970s, with the wide spread of droughts in Africa Thomas *et al.*, (1997) stated that water harvesting is used where rainfall is normally inadequate to meet the requirements of crops. It involves the transfer of runoff water from a catchment area that is not cropped to supplement the rainfall received directly on the area that is cultivated. Abdelhadi *et al.*, (2002) stated that simple water harvesting techniques were often overlooked as an attractive option to increase sorghum packages and help the local people attain some degree of food security and reduce their mass immigration towards large cities (Laflen and Colvin, 1981). Conservation tillage systems not only reduce soil erosion and downstream pollution but also have the potential to generate higher economic returns and better management of soil-water systems on some soils. Currently, conservation tillage systems are the focus of much needed research for producing higher crop yields and preserving soil and water resources for future generations. Kramer and Alberts (1988) reported the results of a six-year study of three tillage systems (moldboard plow, chisel plow and no-till). They found that tillage systems had no significant effect on plant population and grain yield.

In Sudan, sorghum is the main food crop produced in irrigated as well as rain-fed areas. According to FAO (1996) the overall long-term average yield of sorghum is generally very low, estimated as (0.5 ton/ha) which is half of the world average yield and one sixth of that of the developed countries. Abdelhadi *et al.,* (2002) reported that grain sorghum is one of the most important cereals in the Sudan. It is regarded as the second major staple food in the urban areas and the sole major food in most of the rural areas. The total annual average cultivated area is about 2.1 million ha. About 80% of this area is grown under rain-fed conditions. Agabawi *et al.,* (1996) stated that within the rain-fed sector, two production systems exist; the mechanized and traditional systems. The traditional production system consists of small subsistence family farms, with little or no use of machinery and inputs. Under rain-fed agriculture conditions, high water storage in the soil profile is an important factor affecting crop production (Elramlawi *et al*., 2009). Therefore, it is essential that sufficient runoff water and adequately deep soil, with high water storage capacity are available at potential sizes, where water harvesting is to be practiced. Water harvesting includes simple methods used to improve the use of rainwater at a specific site before it leaves a geographical region/ space.

The Chisel plow is an implement with long straight shanks and double ended chisel points which are usually about four to six cm in width. Chisel shanks

are usually mounted on rectangular frame in gangs of five to ten or more shanks at spacing of 30 to 50 cm. The chisel tools can cut, loosen and stir the soil but cause very little turning over. Chisel plows are well adapted to loosening hard dry soils, shattering hard pans and maintaining crop residue cover. Tied ridging - ridges with additional cross ties in the furrows - is an improvement over the simple ridge system. Graded ridges alone may usually lead to an increase of surface runoff compared with flat planting, while tied ridges will decrease the runoff and increase the storage (Hudson, 1987). Tied ridging is also known as furrow blocking, furrow damming, furrow diking, basin listing, basin tillage and micro-basin tillage and usually associated with mechanized farming (Hudson, 1987). It was proved to be most effective water conserving and beneficial technique in the West African Sahel (Hulugalle and Malton, 1990) especially in semi-arid Tanzania where it was initially developed (Lal, 1995). In such system, ridge furrows are blocked with short cross-ties spaced a fixed distance apart to form a series of micro-catchment basins in the field. The cross ties are lower than the main ridges to retain surplus rain water in individual basins, which assures more time for water to infiltrate into the soil, and to allow excess rainwater to flow between the ridge rather than spill over or break the main ridges.

The main objective: to study: the effect of Water harvesting techniques and Chisel plough depth on yield and yield components of Sorghum (*Sorghum bicolor* L.)

MATERIALS AND METHOD

The experimental work was conducted at the pilot farm of the Faculty of Agricultural and Environmental Sciences, University of Gedaref at Twawa area (longitude 35º24′E latitude 14 º 02′N and 602 m above sea level. The soil of the study area is predominantly vertisoils, deep dark coloured clays of montmorillonitic mineralogical origin (clay content is 40-65%). For three consecutive seasons (2009, 2010 and 2011). The land was sloping from east to west with a general slope of 0.04 %. The main treatments, chisel depth with 20 cm (D1), 25cm (D2), and 30 cm (D3) and the sub treatments, tied- ridging spaced at 1 m (TR1), spaced at 2 m (TR2), furrow-ridge with 80 cm spacing ratios 1:1 (RF1) and 160 cm spacing ratios 2:1 (RF2), The latter four treatments were considered as in- situ rain water harvesting techniques, and wide level discing as conventional tillage practice (WLD). The experimental field was arranged in a split-plot design replicated. The total numbers of plots were 45 and each plot size was 6 ×3m. A local sorghum variety “Arfa Gadamak" was grown on 4 August and harvested at 5th of November in the three seasons. Seeding was carried manually in the bottom of the ridge. The spacing between furrow of ridging were 80 cm and 160 cm while between tied-ridging, was 1and 2m. Spacing between holes was 30 cm and 5 seeds per hole and thinned to two plants per hole. Three plants, after sixty days of were randomly selected from each plot for measuring plant height and stem diameter. These plants were cut, tied in bundles, sun dried for ten days and then weighted to give the air-dry yield. A quadrate of (1×1m) was used to give the number of plants/m^2. The collected crop data were plant population, plant height at flowering,

1000 seeds weight, dry matter and total grain yield.

Rain water productivity (WP) was calculated as the ratio of the crop yield to seasonal rain water recived according to Al- jamal *et al.,* (2001) using the following formula

$$WP\ (kg/m^3) = \frac{yield\ (kg\ ha^{-1})}{Total\ water\ applied\ (m^3 ha^{-1})} \quad \ldots\ldots\ldots (1)$$

Analysis of variance appropriate for complete randomized block factorial design was applied by using Statistics 8.

RESULTS AND DISCUSSION

Monthly Amount of Rainfall*:* The amounts of monthly rainfall (mm), measured within the three rainy seasons (2009/2010, 2010/2011 and 2011/2012) are presented in (Figure 1) total annual rainfall was 509.3, 627.8 and 377.1 mm for the first season, second season and third season, respectively (Agricultural Research Corporation, Gadaref). Rainfall records show that the seasons began in May to October; the remaining months of the year were dry.

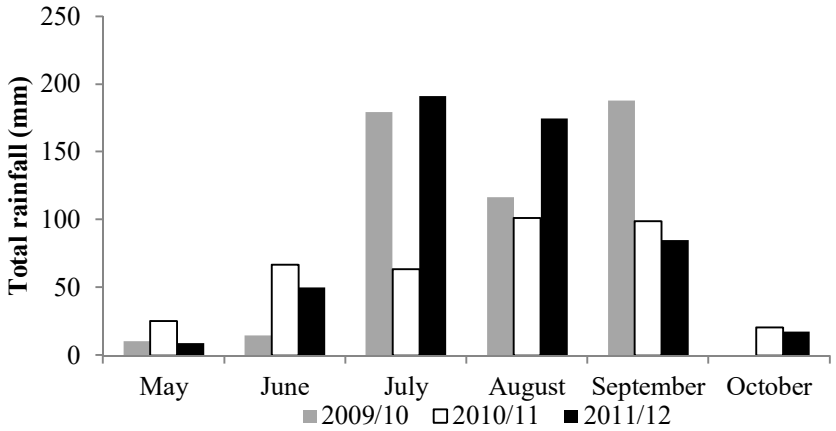

Figure1: Monthly total rainfall for the three seasons

Plant population (plant/m^2): The results of WH techniques on plant population are shown in Table (1). The analysis of variance indicated that there were no significant ($p>0.05$) difference between treatments except in the third season, the result, showed that the highest sorghum plant population (16.31 plant/m^2)for sorghum was produced by (D3) and lowest plant population (12.01 plant/m^2) for sorghum was produced by (D1). The result showed that the plant highest population(16.90 plant/m^2), for sorghum was produced by (TR2) and the lowest plant population (11.30 plant/m^2) for sorghum was produced by (WLD), and shown in Table (2), there were no significant ($p>0.05$) difference between interaction water harvesting techniques and chisel depth, the result showed that the highest plant population for sorghum produced about: 15.33,16.33 and 13.80 plant/m^{2}at TR1 in first, second and third seasons, respectively under chisel depth 30 cm. And WLD produced the lowest plant population about: 14.47, 14.79 and 10.23 (plant/m^2) in first, second and third seasons, respectively, under chisel depth 20 cm. plant population for three chisel depths under different water harvesting.

Table 1: Effect of water harvesting techniques and chisel depth on plant population (plant/m^2)

Treatments	Plant population (plant/m^2)		
	Season 2009/10	Season 2010/11	Season 2011/12
D1	13.40 b	15.63 a	12.01 c
D2	13.62 ab	16.08 a	12.35 b
D3	14.47 a	16.31 a	12.9 0a
LSD	1.02	1.7	0.25
CV	7.29	10.55	1.97
SE±	0.36	0.61	0.089
Sig. level	NS	NS	**
TR1	14.20 a	15.80 a	12.70 a
TR2	14.00 a	16.90 a	13.1 0 a
RF1	14.10 a	15.7 0 a	12.9 0 a
RF2	14.4 0 a	15.7 0 a	12.20 a
WLD	12.50 c	15.00 a	11.30 b
LSD	1.02	1.7	0.25
C.V%	7.29	10.55	1.97
SE±	0.36	0.61	0.07
Sig. level	NS	NS	**

LSD = Least significant difference.
*, ** = means are significant at p≤ 0.05 and p≤ 0.01 respectively. Means with same letter within a column are not significantly different at p≤ 0.05
SE± = Standard Error
D1= chisel depth 20 cm D2 = chisel depth 25 cm 3 = chisel depth 30 cm

Low soil moisture content, formation of soil crusts and inaccurate seeding depth may adversely affect seeds germination and seedlings emergence which may reduce plant population. This result is in agreement with the findings of Ren *et al.,* (2008), there was no significant difference between treatments on plant population.

Table 2: Effect of interaction between water harvesting techniques and chisel depth on Plant population (plant/m^2)

Treatments	Plant population (plant/m^2)								
	Season 2009/10			Season 2010/l1			Season 2011/l2		
	D1	D2	D3	D1	D2	D3	D1	D2	D3
TR1	14.23	12.90	15.33	15.60	15.13	16.33	12.53	11.67	13.80
TR2	13.43	13.70	15.00	16.00	15.90	15.67	12.70	12.68	13.80
RF1	13.87	14.30	14.10	16.13	16.20	14.80	12.30	12.90	13.43
RF2	14.00	15.22	14.67	15.80	15.60	15.67	12.30	12.43	11.79
WLD	14.47	12.67	15.23	14.79	16.20	16.23	10.23	12.10	11.49
Sig. level		NS			NS			NS	
SE±		0.50			0.96			0.53	

Plant height (cm): The results of water harvesting techniques are shown in Table (3). The analysis of variance indicated that there were highly significant (p≤0.01) difference between treatment in first and third season was exception in the second season. The result showed that the plant height (89.80 and 80.10 cm) for sorghum produced in first and third season, respectively by (D3) and the lowest plant height,77.60 and 68.90 (cm) for sorghum were produced by (D1), and the results showed that the height (PH), 86.8 and 76.80 (cm), for sorghum

produced in first and third season, respectively, by (TR1) and (RF2) and the lowest plant height, 76.70 and 67.70 (cm) for sorghum were produced by (WLD).

Table 3: Effect of water harvesting techniques and chisel depth on Plant height (cm)

Treatments	Plant height(cm)		
	Season 2009/10	Season 2010/11	Season 2011/12
D1	77.60 b	88.46 b	68.90 b
D2	82.55b	90.30 a b	73.54 b
D3	89.80a	99.47 a	80.10 a
LSD	5.90	9.50	5.41
CV	7.07	10.15	7.20
SE±	2.30	3.40	1.95
Sig. level	**	NS	**
TR1	86.80 a	96.40 a	74.60 a
TR2	85.60 a	96.00 a	76.40 a
RF1	84.30 a	92.20 a	75.40 a
RF2	83.30 0a	94.30 ab	76.80 a
WLD	76.70 b	84.80 c	67.70 b
LSD	5.90	9.50	5.41
CV	7.07	10.15	7.20
SE±	2.30	3.40	1.95
Sig. level	**	NS	**

LSD = Least significant difference.
*, ** = means are significant at p≤ 0.05 and p≤ 0.01 respectively.
Means with same letter within a column are not significantly different at p≤ 0.05
SE± = Standard Error
D1= chisel depth 20 cm D2 = chisel depth 25 cm D3 = chisel depth 30 cm

The result, shown in Table (4). There were no significant (p>0.05) difference between interaction of in situ water harvesting techniques and chisel depth. The result showed that the tallest plant for sorghum were produced about: 94.4 at TR2, 105.7 at TR1 and 84.1cm at RF1 in first, second and third season, respectively under chisel depth 30 cm while WLD produced shortest plants about: 71.1, 81.6 and 66.1cm in FS, SS and third season respectively, under chisel depth 20 cm. plant height (cm) for three chisel depth under different water harvesting techniques. This result is in agreement with Ibrahim *et al.,* (2016) who reported that tillage (15cm depth) and chicken manure (8ton/ha) treatment significantly increased the plant height (cm), 100-seed weight, panicle weight and grain yield (ton/ha).

Table 4: Effect of interaction between water harvesting techniques and chisel depth on plant height (cm)

Treatments	Plant height(cm)								
	Season 2009/10			Season 2010/l1			Season 2011/l2		
	D1	D2	D3	D1	D2	D3	D1	D2	D3
TR1	81.20	86.40	92.80	89.60	92.80	105.70	69.00	74.00	80.80
TR2	78.50	83.80	94.40	89.40	96.40	103.30	70.20	76.50	82.40
RF1	79.00	82.90	90.90	91.10	89.70	95.70	67.80	74.40	84.10
RF2	78.20	83.40	88.20	90.60	91.00	101.40	71.10	76.40	82.70

WLD	71.10	76.20	83.00	81.60	81.60	91.30	66.10	66.40	70.50
Sig. level		NS			NS			NS	
SE±		2.11			1.78			2.27	

Effect of chisel plough depth × water harvesting techniques on grain yield (kg/ha): The result of grain yield (kg/ha) for three chisel depth under different water harvesting techniques are shown in the Table (5). The analysis of variance indicated that there were significant ($p \leq 0.05$) differences between treatments in the three seasons, the result, showed that the highest grain yield, 2199.8, 2178.1 and 2006.9 (kg/ha), for sorghum was produced in first, second and third season, respectively by (D3) and lowest grain yield (1709.7, 1612.2 and 1525.8 kg/ha),for sorghum was produced by (D1) and the highest grain yield(2128.0, 1963.7 and 1898.6 kg/ha) for sorghum was produced by (RF1), (TR2) and (RF1) in first, second and third season, respectively. The lowest grain yield (1846.7, 1747.0 and 1619.6 kg/ha) for sorghum was produced by (WLD).

Table 5: Effect of water harvesting techniques and chisel depth on Grain Yield (kg/ha)

Treatments	**grain yield** (kg/ha)		
	Season 2009/10	Season 2010/11	Season 2011/12
D1	1709.70b	1612.20 c	1525.80 c
D2	1950.10ab	1782.30 b	1733.40 b
D3	2199.80a	2178.10 a	2006.90 a
LSD	269.80	141.00	135.70
CV	13.63	7.35	7.62
SE±	97.20	50.76	98.90
Sig. level	*	**	**
TR1	1965.60 a b	1942.00 ab	1699.30 cd
TR2	1922.30 b	1963.70 a	1811.40 ab
RF1	2128..00 a	1872.80 b	1898.60 a
RF2	1903.70 b	1928.10 ab	1747.60 bc
WLD	1846.70 b	1747.00 c	1619.60 d
LSD	269.80	141.00	135.70
C.V%	13.63	7.35	7.62
SE±	97.20	50.76	98.90
Sig. level	*	**	**

LSD = Least significant difference.

*, ** = means are significant at $p \leq 0.05$ and $p \leq 0.01$ respectively.

Means with same letter within a column are not significantly different at $p \leq 0.05$

SE± = Standard Error

D1= chisel depth 20 cm D2 = chisel depth 25 cm D3 = chisel depth 30 cm

The results were shown in Table (6), there were no significant ($p>0.05$) difference between interaction of water harvesting techniques (WHT) and chisel depth, except in the third season the result, showed that produced highest yield (kg/ha for sorghum about: 2302.0 at RF1, 2400.3 at TR1 and 2143.7(kg/ha) at TR2 in First, Second and third seasons respectively under chisel depth 30 cm. and WLD produced lowest grain yield (kg/ha) about: 1628, 1505.3 and 1448.3 (kg/ha) in first, second and third season respectively, under chisel depth 20 cm. these results are in an agreement with the results obtained by Omer *et al.,* (2008) and Noralden *et al.,* (2009).

Table 6: Effect of interaction between water harvesting techniques and chisel depth on Grain Yield (kg/ha)

Treatments	Grain Yield (kg/ha)								
	Season 2009/10			Season 2010/11			Season 2011/12		
	D1	D2	D3	D1	D2	D3	D1	D2	D3
TR1	1735.00	1870.70	2193.00	1634.30	1791.30	2400.30	1503.30	1603.00	1991.30
TR2	1667.00	2015.00	2124.00	1617.30	1970.00	2356.70	1455.70	1835.00	2143.70
RF1	1880.30	2201.70	2302.00	1654.70	1776.70	2187.00	1618.00	1957.00	2121.00
RF2	1638.30	1904.30	2168.30	1649.30	1803.70	2333.70	1567.30	1744.30	2014.00
WLD	1628.00	1759.00	2113.70	1505.30	1623.00	2112.70	1448.30	1527.70	1764.70
Sig. level		NS			NS			**	
SE±		109.93			49.17			58.23	

Effect of chisel plough depth water harvesting techniques on 1000 seeds weight(g): The result of 1000 seeds weight (g) for three chisel depth under different water harvesting techniques are shown in Table (7). The analysis of variance indicated that there were highly significant ($p \leq 0.01$) difference between treatment in three seasons, the result showed that the highest 1000 seed weight (27.29, 30.53 and 24.79 g) for sorghum was produced by (D3) in first, second and third season, respectively.

Table 7: Effect of water harvesting techniques and chisel depth on 1000 seeds weight

Treatments	1000 seeds weight (g)		
	Season 2009/10	Season 2010/11	Season 2011/12
D1	22.13c	25.58 b	20.07 c
D2	24.49b	26.92 b	21.99 b
D3	27.29a	30.53 a	24.79 a
LSD	1.60	3.30	093
C.V%	6.58	4.95	4.10
SE±	0.60	1.18	0.33
Sig. level	**	*	***
TR1	25.10 b	27.80 b	22.10 b
TR2	26.20 a	30.00 a	24.0 0 a
RF1	24.70 b	26.90 bc	22.20 b
RF2	24.1 0 b	27.50 b	22.40 b
WLD	23.10 c	26.10 c	20.60 c
LSD	1.60	3.30	0.92
C.V%	6.58	4.95	4.10
SE±	0.60	1.18	0.23
Sig. level	**	*	**

LSD = Least significant difference.
*, ** = means are significant at $p \leq 0.05$ and $p \leq 0.01$ respectively.
Means with same letter within a column are not significantly different at $p \leq 0.05$
SE± = Standard Error
D1= chisel depth 20 cm D2 = chisel depth 25 cm D3 = chisel depth 30 cm

Lowest 1000 seed weight (22.13, 25.58 and 20.07 g), for sorghum was produced by (D1) and the highest 1000seed weight (26.20, 30.00 and 24.00 g), for sorghum was produced by (TR2) in first, second and third season, respectively. The lowest 1000 seed weight (23.10, 26.10 and 20.60 g), for sorghum was produced by (WLD). and shown in the Table (8), there were significant ($p<0.05$) difference

between interaction of water harvesting techniques and chisel depth, except in the first season the result showed that produced highest 1000seed weight for sorghum about: 28.90, 32.90 and 27.00 (g) at TR2 in first, second and third season respectively under chisel depth 30 cm. and WLD produced the lowest 1000 seed weight about: 20.90, 24.40 and 19.10 (g) in first, second and third season, respectively, under chisel depth 20 cm. these results are in an agreement with the results obtained by Noralden *et al.,* (2009).

Table 8: Effect of interaction between water harvesting techniques and chisel depth on 1000 seeds weight

Treatments	1000 seeds weight (g)								
	Season 2009/10			Season 2010/l1			Season 2011/l2		
	D1	D2	D3	D1	D2	D3	D1	D2	D3
TR1	22.10	24.90	28.30	24.70	26.30	32.40	19.40	21.60	25.20
TR2	23.80	25.90	28.90	26.90	30.40	32.90	21.40	23.50	27.00
RF1	22.60	24.30	27.10	26.30	26.20	28.30	20.50	22.10	25.00
RF2	21.30	24.80	26.70	25.70	27.40	31.00	19.60	22.70	25.30
WLD	20.90	22.60	25.40	24.40	24.70	28.00	19.10	20.00	21.40
Sig. level		NS			*			**	
SE±		0.60			0.79			0.56	

Effect of chisel plough depth × water harvesting techniques on Dry matter (kg/ha): The result of dry matter (kg/ha) for three chisel depths under different water harvesting techniques are shown in Table (9).

Table 9: Effect of water harvesting techniques and chisel depth on Dry matter (kg/ha)

Treatments	Dry matter (kg/ha)		
	Season 2009/10	Season 2010/11	Season 2011/12
D1	947.10b	1083.70 c	849.70 c
D2	1032.60b	1171.80 b	918.50 b
D3	1189.40a	1291.50 a	1058.30 a
LSD	106.70	85.60	68.60
C.V%	9.96	7.14	7.18
SE±	38.40	30.80	24.70
Sig. level	**	**	**
TR1	1041.40 b c	1172.60 b	952.90 b
TR2	1132.20 a	1274.6 0 a	1030.80 a
RF1	1046.80 b	1159.2 0 b	945.00 bc
RF2	1067.00 b	1180.4 0 b	915.00 cd
WLD	994.4 0 c	1124.8 0 b	872.30 d
LSD	106.70	85.60	68.60
C.V%	9.96	7.14	7.18
SE±	38.40	30.80	24.70
Sig. level	**	**	**

LSD = Least significant difference.
*, ** = means are significant at p≤ 0.05 and p≤ 0.01 respectively.
Means with same letter within a column are not significantly different at p≤ 0.05
SE± = Standard Error
D1= chisel depth 20 cm D2 = chisel depth 25 cm D3 = chisel depth 30 cm

The analysis of variance indicated that there were highly significant (p≤0.01) differences among treatments in the three seasons. The result showed that the highest dry matter, 1189.40, 1291.50 and 1058.30 (kg/ha), for sorghum was produced by (D3) in first, second and third season, respectively. The lowest dry matter (947.10, 1083.70 and 849.70 kg/ha) for sorghum was produced by

(D1) and the height dry matter (1132.20, 1274.60 and 1030.80 kg/ha) for sorghum was produced by (TR2) in first, second and third seasons, respectively. The lowest dry matter (994.40, 1124.80 and 872.30 kg/ha) for sorghum was produced by (WLD).The result shown in Table (10), there were no significant ($p>0.05$) difference between interaction of water harvesting techniques and chisel depth, except in the third season. These results showed that produced highest dry matter (kg/ha) for sorghum about: 1293.30, 1386.70 and 1168.00 (kg/ha) at TR2 in first, second and third season, respectively under chisel depth 30 cm. WLD produced the lowest dry matter (kg/ha) about: 914.30, 1025.70 and 801.00 (kg/ha) in first, second and third season respectively, under chisel depth 20 cm.

Table 10: Effect of interaction between water harvesting techniques and chisel depth on Dry matter (kg/ha)

Treatment	Dry matter (kg/ha)								
	Season 2009/10			Season 2010/l1			Season 2011/l2		
	D1	D2	D3	D1	D2	D3	D1	D2	D3
TR1	934.30	987.70	1202.30	1030.00	1176.70	1311.00	851.00	906.30	1101.30
TR2	975.70	1127.70	1293.30	1167.00	1270.00	1386.70	910.00	1014.30	1168.00
RF1	965.70	1027.70	1149.00	1106.70	1170.70	1230.00	850.30	905.70	1089.00
RF2	945.70	1062.30	1224.30	1089.00	1187.00	1328.70	836.00	915.30	1013.70
WLD	914.30	959.30	1078.00	1025.70	1055.00	1210.00	801.00	851.00	929.70
Sig. level		NS			NS			*	
SE±		29.15			35.67			23.12	

Effects of chisel ploughing depth on rain water productivity (WP)of Sorghum (Sorghum bicolor L.): The results of (WP) (kg/m^3) for three chisel depths under different water harvesting techniques are shown in Table (11). The analysis of variance indicated that there was highly significant ($p\leq0.01$) difference between treatments in the three seasons. The results showed that the highest (WP), 0.63, 0.63 and 0.56 (kg/m^3), for sorghum was produced by (d_3) in first, second and third respectively. The lowest (WP), 0.47, 0.44 and 0.42 (kg/m^3), for sorghum was produced by (d_1) in first, second and third respectively. Result showed that the height (WP), 0.59, 0.54 and 0.52 (kg/m^3), for sorghum was produced by (TR2) in first, second and third respectively and the lowest (WP), 0.50, 0.48 and 0.45 (kg/m^3), for sorghum was produced by (WL) in first, second and third respectively.

Interaction in Table (12), showed no significant ($p>0.05$) difference between interaction water harvesting techniques (WHT) and chisel depth, in the three seasons on (WP), except in the third season third, the results showed that the highest (WP) 0.60, 0.66 and 0.60 (kg/m^3) for sorghum was produced by TR2 under (d_3) and lowest (WP) 0.44, 0.41 and 0.39 kg/ m^3 was produced by WLD under (d_1).

Table 11: Effect of water harvesting techniques and chisel depth on rain water productivity (WP), in first season

Treatments	WP (kg/m^3)		
	Season 2009/10	Season 2010/11	Season 2011/12
D1	0.47 b	0.44 b	0.42 b
D2	0.54 ab	0.44 b	0.48 b
D3	0.63 a	0.63 a	0.56 a
LSD	0.09	0.06	0.06
CV	17.20	11.04	12.50
SE±	0.034	0.021	0.022
Sig. level	*	**	*
TR1	0.54 bc	0.53 ab	0.46
TR2	0.59 ab	0.54 a	0.52
RF1	0.56 a	0.52 b	0.50
RF2	0.52 cd	0.53 ab	0.48
WLD	0.50 d	0.48 c	0.45
LSD	0.03	0.023	0.03
C.V%	6.0	4.57	6.02
SE±	0.015	0.011	0.014
Sig. level	**	**	**

LSD = Least significant difference.
*, ** = means are significant at p≤ 0.05 and p≤ 0.01 respectively.
Means with same letter within a column are not significantly different at p≤ 0.05
SE± = Standard Error
D1= chisel depth 20 cm D2 = chisel depth 25 cm D3 = chisel depth 30 cm

Table 10: Effect of interaction between water harvesting techniques and chisel depth on WP (kg/m^3)

Treatments	WP (kg/m^3)								
	Season 2009/10			Season 2010/11			Season 2011/12		
	D1	D2	D3	D1	D2	D3	D1	D2	D3
TR1	0.48	0.52	0.63	0.44	0.50	0.65	0.40	0.44	0.54
TR2	0.45	0.56	0.67	0.45	0.52	0.66	0.40	0.51	0.60
RF1	0.51	0.52	0.64	0.46	0.50	0.60	0.44	0.54	0.59
RF2	0.45	0.52	0.60	0.45	0.50	0.64	0.40	0.48	0.56
WLD	0.44	0.48	0.58	0.41	0.45	0.58	0.39	0.42	0.49
Sig. level		NS			NS			*	
SE±		0.019			0.014			0.017	

CONCLUSIONS

The study evaluated the effect of in situe water harvesting techniques with three chisel plough depths on the production of rain-fed sorghum. On the basis of significant results obtained from this investigation, the following conclusions could be drawn:

i. Combination of water harvesting techniques and chisel ploughing depth of 20 cm resulted in the lowest sorghum production.

ii. Combination of water harvesting techniques and chisel ploughing depth of 30 cm resulted in the highest sorghum production.

iii. Combination of water harvesting techniques tied-ridge 2m (TR2) produced the highest sorghum grain yield.

iv. The highest rain water productivity was obtained at tied-ridge 2m (TR2).

v. The lowest productivity and WP was obtained at (WLD).

RECOMMENDATIONS

i. In the rain-fed areas the chisel plowing depth need to be applied as to prepare the land for highest sorghum production.

ii. To increase the production of rain-fed sorghum, the chisel plowing at depth of 30 cm must (D3) need to be used to couple with water harvesting technique to increase crop productivity and maximize prepetition use efficiency.

iii. The effect of *in-situ* water harvesting and conservation tillage techniques must be studied in connecter with the application of different fertilizers and their impact on Soil erosion.

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