Pak. J. Agri. Sci., Vol. 51(4), 779-788; 2014
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
http://www.pakjas.com.pk

IMPACT OF DIFFERENT WATER HARVESTING TECHNIQUES ON SOIL MOISTURE CONTENT AND YIELD COMPONENTS OF SORGHUM

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Rainwater harvesting (RWH) could be the best alternative for water resources, which affects the yield and productivity of Sorghum *(Sorghum bicolor L.*). Therefore, field studies were conducted in North Kordofan area, Western Sudan, on a sandy clay loam soil during 2012 and 2013 growing seasons, in which the effects of five water harvesting techniques (WHTs) for growing sorghum including mulching, intercropping, stone barriers, crescent and L-shape were investigated. The moisture content of the soil was measured at three periods before crop sowing (P_1), at mid-season (P_2) and after harvest (P_3) and at four soil depths (0-15, 15-30, 30-60 and 60-90 cm). The results revealed that, the soil and plant parameters were significantly influenced by the WHTs during both growing seasons through improving the structure, infiltrability, and water storage capacity of the soil in relation to the control. The variability of the soil moisture content (SMC) and plant parameters increased during the drier season 2012 and decreased during the wetter season 2013. Soil depth, measurement period and their interaction had highly significant effects on SMC during both growing seasons. Differences among the WHTs were more obvious in the topsoil layer (0-30 cm) with no significant differences below 30 cm depth. Straw mulching conserved more moisture within one soil profile, particularly at the medium and lower depths (30-90 cm). It also consistently captured more run-off water than the other techniques; at all stages of plant growth, in both growing seasons followed by earth and stone bunding. This was clearly reflected by better crop establishment and yield components of sorghum, hence generate higher gross returns. In conclusion, the study revealed the potential advantages of WHTs for semi-arid zones and in particularly for Northern Kordofan, Sudan with reference to the rationale for adopting WHTs and enhance sorghum yield.
Keywords: Soil moisture, water harvesting techniques, sorghum

INTRODUCTION

About 95% of the world agricultural land and 83% of world's cropland depends on precipitation as the sole source of water (Wood *et al*., 2000). Food security and poverty alleviation, the 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 84 million ha are cultivable land or suitable for agriculture. 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).

Soil and water, which are the basic factors in crop production, are becoming major problems all over the world. Proper management of those valuable resources is vital to sustain long-term agricultural productivity. Million hectares are degrading as result of erosion, moisture deficit and loss of fertility, leading to decline in productivity (Morgan, 2005; Noellemeyer *et al*., 2006). The problem is most severe in the arid and semi-arid areas, where the problems of environmental degradation, drought and population pressures are most evident (Bridges and Oldeman, 2001). Sloping lands are particularly vulnerable to erosion and moisture deficit. Western Sudan is characterized by sloping and capping nature of land. The, presence of various valleys and seasonal watercourses, which are usually poorly managed, has seen to mean annual rainfall had declined from more than 650 mm during the period between the mid 40,s and the mid 50,s, to less than 500 mm during the 80,s and early 90,s (FAO, 2006).

Such fluctuations may have negative implications on water resources and agricultural production. This urges maximum utilization of RWH for crop production through different conservation measures (Salas *et al*., 2009). Water harvesting incorporates a broad set of techniques and methodologies in crop production systems that can be presented main domains namely, in-situ rainwater harvesting, internal (Micro) catchment and External (Macro) catchment rainwater harvesting, runoff-farming systems and spate irrigation (flood water harvesting) (FAO, 1993; Critchley and Siegert, 1991). Hence, each of these techniques tends to store more water within the soil and eliminate most of runoff water. The traditional conservation measures may be replaced or improved upon. The objective of the present study, therefore, is to adopt a cost effective and socially acceptable rain water harvesting measures with the intention of raising and sustaining the sorghum productivity in Northern Kordofan, Western Sudan. The objectives are: (1) To investigate and evaluate the effect of five water harvesting techniques (WHTs) namely mulching, intercropping, stone barriers, crescent and L-shape and their interaction with land slope and soil depth on soil moisture content throughout the measurement periods (before sowing, mid-season and after harvest), in improving water conservation and the yield and yield components of sorghum crop under rain-fed conditions; (2) To study the optimizing use of run-off water on different sloping land through different water harvesting techniques; and (3) Providing alternative means of soil-water conservation to be adopted by farmers.

MATERIALS AND METHODS

***Study area and soil properties*:** A field experiment was conducted in the year 2012 and 2013 growing seasons at North Kordofan (latitude. 16° 25' N; longitude. 32° 15' E), Western Sudan, annual rainfall average between 400-500 mm and mean air temperature 28-30°C. Lands are gently sloping (1-3%), shallow compact and derived mainly from basement complex rocks and volcanic material. A sample of the soil had been analyzed based on the method adopted by Tandon (1993), which are shown in (Table 1).

***Design of experiments*:** The experiment consisted of five water harvesting techniques (WHTs) and control and three gradient of land slope (S_1 0.97%, S_2 1.36% and S_3 1.76%) within which the replications were nested. 24 plots (4 m x 30 m each) were laid out at each slope with spacing of 2 m between plots while 4 m between replications were kept as buffer zones. The borders of each plot were raised to prevent runoff.

The WHTs used were as follows: control in which measure are used T_0: no conservation measures; mulching T_1: with millet straw at 4.2 t ha^{-1}, in bunds (45 cm wide and 25 cm apart), providing 63 % surface cover. T_2: intercropping local cultivars of sorghum, (cv. Fasiekh, Sibyan Sawa) with groundnut, Arachis hypogaea (cv. Sodari) in 1:1 row ratio; T_3: simple stone barriers (stone with 10-30 cm) in diameter was placed along the contour, at horizontal intervals of 10 cm, across the slope. The stones were set into 5 cm deep and 30 cm wide furrows, forming 25 cm high bunds and T_4: and T_5 Crescent-shaped (T_4) and L-shaped (T_5) earth bunds were constructed across the slope with their arm tips lying on the contour and a shallow furrow at the up slope side. The bunds (40 cm base width, 15 cm top width and 30 cm height) were spaced at 10 m horizontal intervals down the slope. They were provided with 40 cm wide and 15 cm high outlet at opposite sides of successive bunds. In all techniques sorghum was planted flat on rows at a seed rate of 9 kg ha^{-1}, 5-7 grain/hill thinned to three plants/hill three weeks after sowing. In the intercropping technique, groundnut was sown manually at a rate of 60 kg ha^{-1} with 2 seeds/hill.

Intra and inter-row-spacing's of 70 and 40 cm and 70 and 25 cm were allowed respectively, for monocropped and intercropped sorghum, and groundnut. Sorghum and groundnut were sown on 7th July 2012 and 21st July 2013.

No fertilizers were applied and two hoe-weedings were done at 25 and 45 days after sowing in both the growing seasons. Plant height at 14-day intervals, number of tillers/plant and the percentage of plants producing heads were recorded from 20 randomly selected plants from each plot. Immediately after harvesting the earth heads, the plants from the center 20m^2 (2m x 10m) of each plot area were cut at ground level and weighed for fresh matter weight determination. The same plants were air-dried for three weeks and weighed for dry matter determination. Final harvests for grain were taken from the whole plot area on 17th November (129 days after sowing) and 7st October (95 days after sowing) in the first and second seasons, respectively. Groundnut plants were uprooted 91 and 95 days after sowing in the first and second season, respectively,

Table 1. Physical characteristics of the soil

Properties	**Soil depth cm**			
	0-15	**15-30**	**30-60**	**60-90**
Total sand (%)	66.0	55.3	50.0	44.7
Total silt (%)	14.0	15.3	17.7	16.7
Total clay (%)	20.0	29.4	32.3	38.6
Textural class	Sandy loam	Sandy clay	Sandy clay	Sandy clay
Dry bulb density (g cm^{-3})	1.52	1.54	1.61	1.64
Particle density (g cm^{-3})	2.57	2.58	2.58	2.58
Total porosity (%)	41.0	40.2	37.6	36.6
Moisture content (v/v)	4.90	8.02	10.79	13.92
Hydraulic conductivity (cm/hr)	0.77	0.47	0.53	0.41
Electrical conductivity (EC) (mmohs)	0.02	0.03	0.03	0.05
Water holding capacity (mm/m)	120	165	-	-
pH: paste	5.9	6.2	6.2	6.1
pH: 1: 5: (soil: water)	6.8	6.9	6.9	7.2

Table 2. Meteorological data of the experimental area in the growing seasons

Month		June	July	Aug.	Sept.	Oct.	Nov.	Total
		Season 2012						
Relative humidity (%)	Max.	73	88	84	80	76	63	
	Min.	48	52	63	61	51	33	
	Mean	60.3	74.8	77.5	71.3	62.1	45.4	
Air temperature (°C)	Max	35.9	32.2	31.4	35.1	35.4	34.6	
	Min.	22.3	20.3	19.6	19.3	18.4	14.1	
	Mean	26.3	24.4	24.2	25.0	24.8	21.6	
open evaporation (mm/day)	Max	12.1	12.6	11.7	11.8	10.9	10.7	
	Min.	5.0	4.3	4.3	5. 4	6.1	5.8	
	Mean	8.6	8.0	6.6	8.2	8.5	8.7	
Rainfall (mm)	-	24.4	191.2	89.1	43.8	23.4	16.8	388.7
No. of rainy days	-	6	14	18	10	4	1	53
Average wind speed (km/day)	2 m	112	125	132	139	174	181	-
	0.9 m	77	85	88	92	109	113	-
		Season 2013						
Relative humidity (%)	Max.	84	91	92	91	88	59	
	Min.	33	54	79	65	51	33	
	Mean	54.8	73.8	87.8	79.7	72.4	43.3	
Air temperature (°C)	Max	37.4	33.1	29.1	30.9	34.8	35.4	
	Min.	24.9	22.1	19.9	14.5	9.2	12.5	
	Mean	26.6	24.5	22.4	23.2	22.7	19.9	
Open evaporation (mm/day)	Max	11.8	10.6	10.0	9.0	10.0	10.4	
	Min.	6.4	4.5	4.3	5.4	4.7	5.4	
	Mean	9.5	7.6	6.2	6.4	7.7	7.4	
Rainfall (mm)	-	56.0	154.9	267.2	78.5	37.0	-	563.6
No. of rainy days	-	7	10	25	9	4	-	55
Average wind speed (km/day)	2 m	157	181	146	109	112	122	
	0.9 m	101	123	92	70	62	74	

and the total pod yields were determined.

***Sampling and measurement*:** Meteorological data for both growing seasons Table 2 were obtained from a meteorological station established within the experimental site. Soil samples were randomly taken from four depths (0-15, 15-30, 30-60 and 60-90 cm) at three locations per plot for gravimetric moisture determination. Sampling was done at three measurement periods (before sowing the crop P_1, at mid-season P_2 and after harvest P_3) and one-day after each of four rain events, during each season, which corresponded to four stages as suggested by Dorrenbos and Pruitt (1977). The samples were weighed fresh, oven-dried at 105℃ for 24 hours and reweighed, and then gravimetric moisture content was calculated by expressing the percentage moisture on dry mass basis (Michale, 1978). The soil moisture contents per unit mass were converted to volumetric data using bulk density values corresponding to each technique. The bulk density of the soil was also measured up to a depth of 90 cm, in the middle of both growing seasons, with the core sampler method (Blake and Hartge, 1986; Manrique and Johnes, 1991). Surface runoff data were also recorded.

***Data analysis*:** The data were analyzed by (ANOVA), using SPSS software (version 16.0, SPSS Inc., Chicago, IL, USA). Differences between means were considered significant at $P \leq 0.05$, while the treatment means were compared by Duncan's Multiple Range Test (DMRT).

RESULTS

Land slope and its interaction with WHTs, soil depth and measurement period had no significant effect on soil moisture content (SMC) during both the seasons Table 3 but the impact of the measurement period on SMC in the first and second seasons (Fig. 1). At all slopes, SMC was higher in the 2013 than in the 2012 growing season. The results obtained revealed significant differences ($P \leq 0.01$) in soil moisture reserves under treatment with different WHTs for all plant growth stages Table 4 while the interaction of the measurement periods with WHT and soil depth were highly significant ($P \leq 0.05$) during both growing seasons Table 5. T_1 consistently retained more runoff water Table 6 and produced higher moisture content than the other techniques, in the both seasons, followed by T_2 and T_3 particularly at the initial and development stages. T_4 ranked the second to T_1 in moisture conservation, although T_4 provided more moisture at upper layers (0-15 cm) immediately above the bunds, which was reflected by the good crop performance and yield. Moreover, T_1 stored more water in the medium and lower

Table 3. Average values of SMC as influenced by slope gradient, WHT, soil depth and measurement period

Treatments	2012				2013			
WHT	**Slope 1**	**Slope 2**	**Slope 3**	**Mean**	**Slope 1**	**Slope 2**	**Slope 3**	**Mean**
T0	8.20	8.22	8.20	8.21d	9.86	9.81	9.69	9.79d
T1	9.14	9.15	9.00	9.09a	10.87	10.80	10.95	10.87a
T2	8.37	8.35	8.42	8.38c	10.24	10.35	10.33	10.31c
T3	8.79	8.74	8.76	8.76b	10.63	10.66	10.50	10.60a
T4	9.03	9.09	9.09	9.07a	10.96	10.87	10.71	10.84b
T5	8.90	8.92	8.96	8.92b	10.78	10.71	10.72	10.74ab
Mean	8.73b	8.74b	8.74b		10.56c	10.53c	10.49c	
±SE of WHT × slope		±0.084				±0.117		
Soil depth (cm)								
0- 15	5.01	5.01	4.98	5.00d	7.03	7.01	6.93	6.99d
15- 30	7.93	7.90	7.88	7.90c	10.78	10.74	10.76	10.76c
30- 60	10.55	10.57	10.58	10.57b	12.12	12.09	12.01	12.07b
60- 90	11.53	11.50	11.52	11.52a	12.30	12.20	12.24	12.25a
Mean	8.76c	8.74c	8.74c		10.56c	10.56c	10.49c	
±SE of soil depth × slope		±0.068				±0.055		
Measurement period (P)								
Before sowing	5.98	5.90	5.93	5.94e	6.55	6.50	6.50	6.52c
Mid-season	10.77	10.80	10.77	10.78a	13.52	13.54	13.43	13.50a
After harvest	9.52	9.53	6.52	9.52b	11.60	11.56	11.53	11.56b
Mean	8.76d	8.74d	8.74d		10.56d	10.53d	10.49d	
±SE of measurement period × slope		±0.001				±0.083		
CV (%)		6.63				7.68		

a-e: for each growing season, mean followed by the same letters (s) are not significantly different at 5 % level according to DMRT. When no letters are shown, the interaction means were not significant.

layers of the soil (30-90 cm).

In the middle of both the seasons, soil moisture was in the order $T_1 > T_4 > T_5 > T_3 > T_2 > T_0$. Soil depth was also highly significant ($P \leq 0.01$) in both the growing seasons, while its interaction with WHT was highly significant in the second season only (Table 7).

For all techniques, average SMC tended to increase with increasing soil depth and differences among WHTs were more obvious in the top soil layer (0-15 cm) then decreased at lower layers (below 30 cm depth). However, highest values were recorded by T_1 and T_4 this can be notice clearly in season 2013, (Fig. 2).

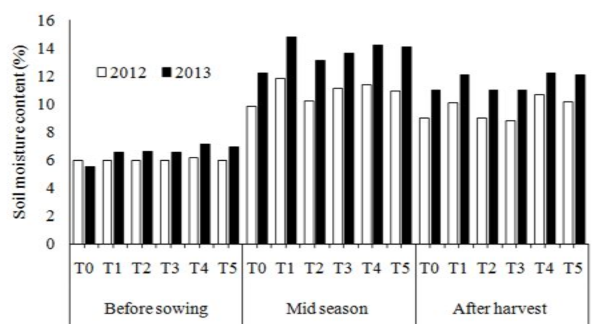

Figure 1. Soil moisture content as influenced by measurement period

Table 4. Analysis of variance for SMC at four crop growth stages during 2012 and 2013 growing seasons

S.O.V.	D.F	Initial stage		Development squares		Mid-season		Final stage	
Season		**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Replication	9	0.336^{Ns}	0.137^{Ns}	0.152^{Ns}	0.146^{Ns}	0.369^{Ns}	0.1474^{Ns}	0.1991^{Ns}	0.1968^{Ns}
Slope (S)	2	0.644^{Ns}	0.839^{Ns}	0.789^{Ns}	0.845^{Ns}	0.269^{Ns}	0.6924^{Ns}	0.2023^{Ns}	0.3995^{Ns}
Technique (T)	5	75.217**	74.448**	91.237**	80.596**	77.305**	61.639**	16.0354**	80.946**
Depth (D)	3	1091.80**	666.601**	374.115**	845.442**	363.999**	530.326**	655.798**	94.093**
SxT	10	0.744^{Ns}	0.601^{Ns}	1.318^{Ns}	0.911^{Ns}	o.7702^{Ns}	0.2933^{Ns}	0.7583^{Ns}	0.5548^{Ns}
SxD	6	0.963^{Ns}	0.044^{Ns}	0.575^{Ns}	0.580^{Ns}	0.332^{Ns}	0.1813^{Ns}	0.3452^{Ns}	0.1711^{Ns}
TxD	15	5.907**	3.241*	2.452*	1.785^{Ns}	5.026**	1.4521^{Ns}	2.5377^{Ns}	3.8533**
SxTxD	30	0.128^{Ns}	0.294^{Ns}	0.198^{Ns}	0.393^{Ns}	0.4787^{Ns}	0.4483^{Ns}	0.3675^{Ns}	0.2556^{Ns}
Error	207	0.817	0.892	1.412	2.065	0.5567	1.8950	1.2933	0.9030

Ns: Not significant, *: Significant at $P \leq 0.05$, **: Significant at $P \leq 0.01$

Table 5. Average values of SMC as influenced by WHT, soil depth and measurement period

Treatment	2012			Mean	2013			Mean
	P_1	P_2	P_3		P_1	P_2	P_3	
Water harvesting technique								
		±0.084		±0.048		±0.117		±0.067
T_0	5.95^{n}	9.82^{k}	8.95^{m}	8.24^{c}	6.28^{r}	12.40^{l}	10.67^{p}	9.79^{d}
T_1	5.97^{n}	11.42^{g}	9.89^{k}	9.09^{a}	6.38^{qr}	14.22^{h}	12.07^{lm}	10.87^{a}
T_2	5.86^{n}	10.33^{j}	8.96^{m}	8.38^{c}	6.43^{qr}	13.29^{k}	11.20^{o}	10.31^{c}
T_3	5.88^{n}	10.89^{i}	9.53^{l}	8.76^{b}	6.65^{qr}	13.49^{jk}	11.66^{n}	10.60^{b}
T_4	6.03^{n}	11.19^{gh}	10.00^{k}	9.07^{a}	6.73^{q}	13.90^{hi}	11.86^{mn}	10.85^{a}
T_5	5.93^{n}	11.02^{hg}	9.82^{k}	8.92^{b}	6.64^{qr}	13.64^{ij}	11.91^{mm}	10.74^{ab}
		±0.034					±0.048	
Mean	5.94^{g}	10.78^{d}	9.52^{e}		6.52^{g}	13.49^{c}	11.56^{f}	
Soil depth (cm)								
		±0.068		±0.039		±0.095		±0.055
0-15	3.20^{s}	7.35^{o}	4.45^{r}	5.00^{d}	3.92^{p}	11.06^{k}	5.99^{n}	6.99^{d}
15-30	5.20^{q}	9.37^{l}	9.13^{m}	7.90^{c}	5.60^{o}	14.38^{h}	12.30^{j}	10.76^{c}
30-60	6.76^{p}	12.84^{i}	12.10^{k}	10.57^{b}	7.83^{m}	14.40^{h}	13.76^{l}	12.07^{b}
60-90	8.58^{a}	13.56^{h}	12.41^{j}	11.52^{a}	8.73^{l}	13.90^{l}	14.21^{h}	12.28^{a}
		±0.034				±0.048		
Mean	5.94^{g}	10.78^{e}	9.52^{l}	-	6.52^{g}	13.49^{e}	11.56^{f}	-
C.V. %			6.63			7.678		

a-s: for each growing season, means followed by the same letter (s) are not significantly different ad 5 % level according to DMRT. When no letters are shown, the interaction means were not significant.

Table 6. Percentage retained runoff and soil loss during different storms and crop growth stage

Crop growth stage	Treatment	2012			2013		
		Rainfall intensity	**Retained runoff**		**Rainfall intensity**	**Retained runoff**	
		(mm/h)	**mm**	**%**	**(mm/h)**	**mm**	**%**
Initial stage	T_0	31.5	13.1	41.30	16.4	4.6	35.22
	T_1		18.4	57.65		7.1	45.72
	T_2		13.8	43.42		4.8	36.69
	T_3		15.1	47.28		5.5	42.55
	T_4		16.8	52.57		6.4	49.59
	T_5		16.1	50.70		6.3	48.20
Development stage	T_0	17.1	8.9	61.66	29.5	13.3	22.73
	T_1		11.3	78.47		17.9	30.58
	T_2		9.4	65.27		14.9	24.85
	T_3		9.7	67.64		15.4	26.14
	T_4		10.4	72.22		16.6	28.33
	T_5		10.1	70.42		15.8	26.90
Mid-season stage	T_0	29.6	10.1	59.84	22.4	8.6	38.12
	T_1		12.6	75.22		11.0	48.37
	T_2		11.0	65.14		9.4	41.67
	T_3		11.2	66.35		10.0	43.92
	T_4		11.8	70.45		10.4	45.93
	T_5		11.6	69.03		10.2	45.13
Late season stage	T_0	20.6	14.0	63.25	17.8	8.6	38.12
	T_1		16.2	73.35		11.0	48.37
	T_2		14.7	66.58		9.4	41.67
	T_3		15.3	69.35		10.0	43.92
	T_4		15.7	70.78		10.4	45.93
	T_5		15.6	70.47		10.2	45.13

Table 7. Average values of SMC as influenced by soil depth and WHT

WHT	Soil depth									
	2012					2013				
	0-15	15-30	30-60	60-90	Mean	0-15	15-30	30-60	60-90	Mean
	±0.097				±0.048	±0.135				±0.067
T_0	4.36	7.56	9.82	11.23	8.24^{c}	6.65^{q}	9.76^{o}	10.88^{nn}	11.94^{l}	9.79^{d}
T_1	5.39	8.21	11.02	11.75	9.09^{a}	6.96^{pq}	11.28^{m}	12.75	12.50^{ljk}	10.87^{a}
T_2	4.47	7.53	10.23	11.31	8.38^{c}	6.68^{q}	10.45^{n}	11.91^{l}	12.18^{ijkl}	10.31^{c}
T_3	5.07	7.95	10.58	11.46	8.76^{b}	7.09^{pq}	10.88^{mn}	12.13^{kl}	12.30^{ijkl}	10.60^{b}
T_4	5.41	8.22	10.93	11.72	9.07^{a}	7.34^{p}	11.19^{m}	12.42^{ijk}	12.42^{ijk}	10.85^{a}
T_5	5.29	7.95	10.83	11.63	8.92^{h}	7.20^{p}	11.09^{m}	12.34^{ijkl}	12.32^{ijkl}	10.74^{ab}
			±0.039					±0.055		
Mean	5.00^{g}	7.90^{f}	10.57^{c}	11.52^{d}		6.99^{h}	10.76^{g}	12.07^{f}	12.28^{c}	
C.V. %			6.63					7.68		

a-q: for each growing season, means followed by the same letter (s) are not significantly different at 5 % level according to DMRT. When no letters are shown, the interaction means were not significant.

Table 8. Average growth, and yield parameters of sorghum during entire experimental period as affected by WHTs

WHTs	Final seeding emerg. (%)	Plant density m^{-2}	No. of total tiller /plant	No. of effective tiller /plant	Fresh matter weight (t ha^{-1})	Dry matter weight (t ha^{-1})	Plant height at harvest (cm)	Head length (cm)	Plant produc. heads (%)	Head weight (g)	100-grain weight (g)	Total grain yield (t ha^{-1})
						2012						
T_0	80.86^{b}	12.21^{c}	1.87^{b}	0.47^{c}	3.60^{b}	0.904^{c}	133.41^{c}	14.21^{bc}	25.14^{b}	85.78^{b}	27.22^{c}	0.21^{b}
T_1	84.69^{a}	13.17^{a}	2.15^{a}	0.74^{a}	4.45^{a}	1.539^{a}	198.96^{a}	15.68^{a}	34.42^{a}	95.54^{a}	32.57^{a}	0.38^{a}
T_2	81.11^{b}	12.42^{b}	1.91^{b}	0.48^{c}	3.60^{b}	0.907^{c}	136.62^{c}	14.03^{c}	24.96^{b}	85.61^{b}	27.59^{c}	0.21^{b}
T_3	83.64^{a}	13.05^{a}	2.06^{a}	0.68^{b}	4.38^{a}	1.474^{b}	165.95^{b}	15.13^{ab}	33.26^{a}	93.07^{a}	30.22^{b}	0.37^{a}
T_4	83.75^{a}	13.11^{a}	1.12^{a}	0.72^{ab}	4.44^{a}	1.531^{a}	193.35^{a}	15.51^{a}	33.83^{a}	94.64^{a}	31.16^{b}	0.38^{a}
T_5	83.67^{a}	13.00^{a}	2.08^{a}	0.71^{ab}	4.40^{a}	1.489^{ab}	164.73^{b}	15.25^{a}	33.72^{a}	94.17^{a}	3046^{b}	0.38^{a}
S.E±	0.393	0.140	0.044	0.016	0.059	0.018	2.962	0.305	1.166	0.736	0.392	0.005
C.V.%	1.64	3.79	7.51	8.48	4.93	4.72	6.20	7.06	13.07	2.79	4.54	4.83
						2013						
T_0	83.55^{c}	14.82^{a}	2.30^{b}	2.27^{a}	9.68^{b}	4.019^{a}	111.84^{c}	13.78^{a}	82.09^{a}	51.38^{a}	23.52^{a}	1.72^{c}
T_1	92.78^{a}	15.72^{a}	2.89^{a}	2.39^{a}	10.71^{a}	4.243^{a}	133.04^{a}	14.14^{a}	82.88^{a}	53.43^{a}	23.75^{a}	1.83^{a}
T_2	84.95^{c}	15.13^{a}	2.32^{b}	2.30^{a}	10.08^{ab}	4.134^{a}	126.00^{c}	13.93^{a}	82.28^{a}	52.38^{a}	23.66^{a}	1.73^{bc}
T_3	88.00^{b}	15.43^{a}	2.79^{a}	2.31^{a}	10.37^{ab}	4.184^{a}	126.49^{c}	13.84^{a}	82.39^{a}	51.98^{a}	23.65^{a}	1.76^{abc}
T_4	88.08^{b}	15.50^{a}	2.82^{a}	2.36^{a}	10.59^{a}	4.189^{a}	130.86^{ab}	14.00^{a}	82.84^{a}	52.82^{a}	23.70^{a}	1.81^{ab}
T_5	87.78^{b}	15.43^{a}	2.82^{a}	2.33^{a}	10.56^{a}	4.214^{a}	128.54^{bc}	13.95^{a}	82.74^{a}	52.46^{a}	23.61^{a}	1.79^{abc}
S.E±	0.885	0.256	0.058	0.0350	0.220	0.137	1.394	0.280	0.502	0.767	0.334	0.025
C.V.%	3.50	5.78	7.54	5.14	7.38	11.40	3.83	6.96	2.11	5.07	4.89	4.86

a-c: for each growing season, means followed by the same letter (s) are not significantly different at 5 % level according to DMRT.

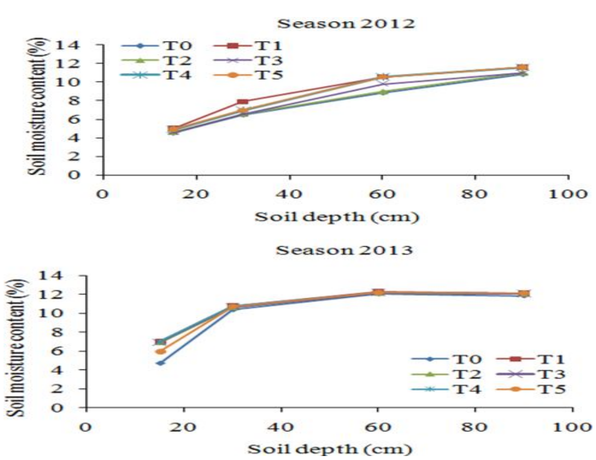

Figure 2. Soil moisture content as affected by soil depth.

The SMC was maximum in all plots treated with straw mulch at various crop growth stages and soil depths. T_1 increased soil water storage by 29.1, 35.8, 30.1 and 22.4% in the first cropping season and by 29.5, 24.9, 20.2, and 26.2% in the second cropping season during the initial, development, mid-season and late season stages, respectively, as compared to T_0. T_2 differed slightly, but contribute significantly in moisture content, from T_0 at initial growth stage and their differences increased with time throughout the growing season with improved intercrop canopy cover. Moisture content also increased with increasing soil depth to a maximum value at 15-30 cm depth and then decreased, but all techniques accumulated water in the lower layers with time, which are depicted in (Fig. 3).

Table 9. Average production costs and returns (Sudanese pound/ha) for Sorghum under different WHTs

	2012						2013					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
Total cost*	9001	21680	13868	11561	15561	15561	15712	24215	22072	17232	22392	22292
Gross returns**	8961	16948	15456	13917	15868	15698	23168	30702	35602	26764	29014	28766
Net benefit	-	-	1578.7	2355.7	306.7	136.7	7456	6487	13530	9532	6622	6474

Sudanese pounds: 2.80 US$ = 1.00 (2009); *: including costs of ploughing, bund construction and maintenance, mulching material, mulch management and other farm practices; **: including returns from sorghum (grain and straw) and groundnut (pods and vine).

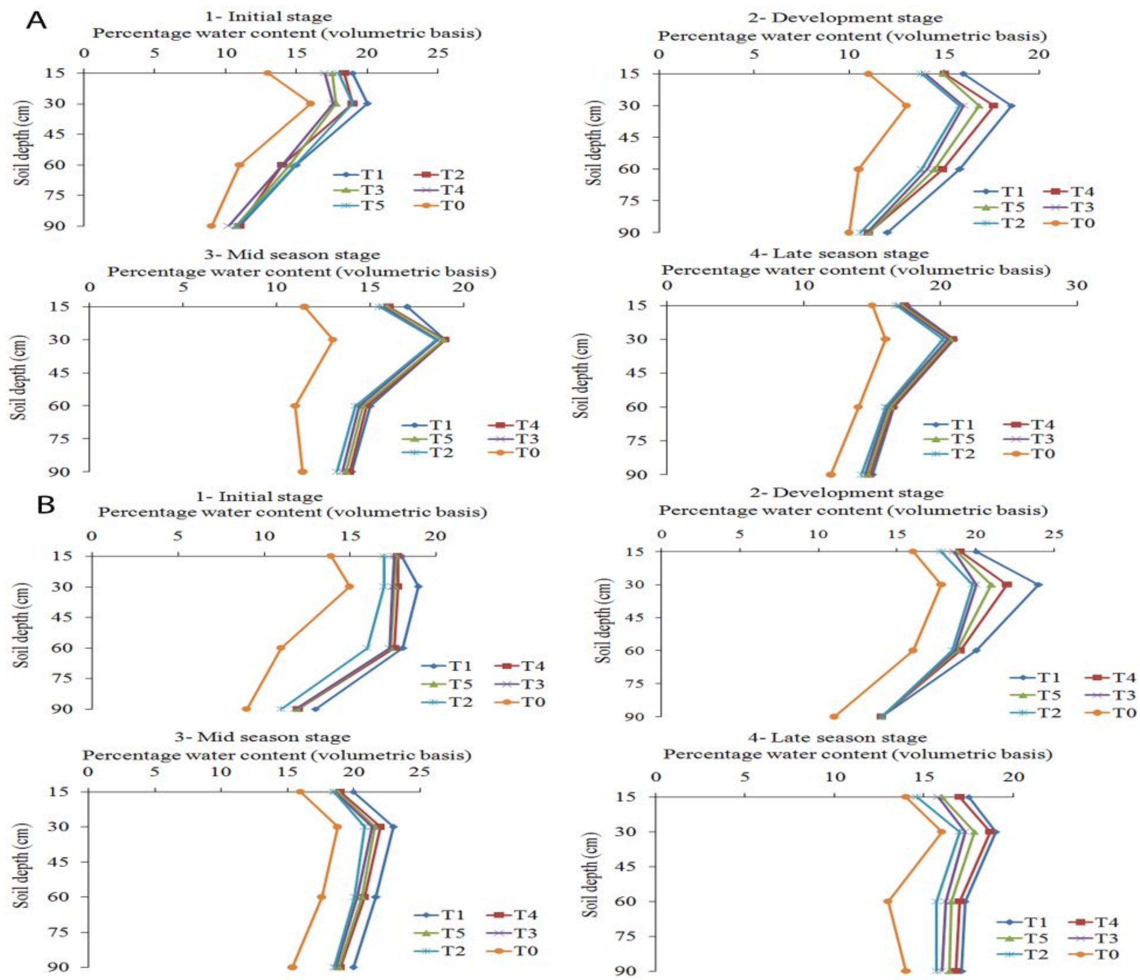

Figure 3. Volumetric SMC at four plant growth stages as affected by WHTs in seasons 2012 (A) and 2013 (B)

Data of plant variables are presented in (Table 8). The sorghum respond in the same way to the slope gradients and WHTs even though their individual heights and maturity periods differed. The second season showed better results than the first season for all treatments. In both growing seasons, plant variables were less affected by land slope due to the non-significant effect of land slope and its interaction with WHT. On the other hand, all sorghum variables were significantly affected ($P \leq 0.01$) by the WHT. The influence of WHT was consistence with the conserved moisture in the soil profile. T_1 consistently improved plant performance and gross returns during both growing seasons, although was not significantly differ from bunded plots which was not differ from each other in most cases. T_4 ranked second to T_1 in all plant variables. On the other hand, T_0 resulted in the poorest plant performance and gross returns, particularly in the first season, although was not significantly differ from T_2. In spite of the worthy results and gross returns from T_1 and T_4, T_3 and T_2 gave the highest net benefits in the first and second seasons, respectively (Table 9).

DISCUSSION

The soil under study was characterized by low water holding capacity, which may be a result of the low porosity, low hydraulic conductivity, high bulk density and soil strength (Shi and Shao, 2000). As a consequence the water flow into the soil will be impeded (Hill, 1990).

The non-significant effect of land slope on soil moisture was expected and attributed mainly to the reduced slope length and consequently the differences between slopes with different degrees as a result of application of conservation measures, this confirm by Critchley and Siegert (1991) and FAO, (1993). Nádia and Paiva (2007) noted that, installation of mechanical conservation measures on sloping lands can break up the slope into segments smaller in the length than is required to generate overland flow and erosion hazards. On the other hand, WHTs under study showed highly significant differences in both growing seasons. They improved water storage capacity of the soil through reduction of runoff and surface sealing and permitting more time for ponded water to infiltrate. These were in line with the previous findings of Lal (1998), Tesfai and Stroosnijder (2001) and Wilson et al. (2004). T_1 treatment was found to be superior in runoff retention and moisture storage, at all soil depths, immediately after rainfall and during wet periods. This was attributed mainly to the porous character, improved structure and permeability under mulch, as a result of soil fauna activity and probably partial decomposition of straw mulch (Lal, 1998; Yajun et al., 2009). Additional factors contributing to the superiority of mulching over the other techniques were suppression of evaporation rate within limited periods of time after rainfall and protection of the soil surface from the beating action of raindrops (Gardner *et al.*, 1999). Elwell and Stocking (1976) suggested that, for adequate soil protection, water retention and proper plant growth the straw mulch should be applied to cover 70-75% of the soil surface, while Sur et al. (1992) found 36% reduction in runoff with mulch applied in bands and provided only 20% surface cover. Other reports, (Daisley *et al.*, 1988; Papendick and Parr, 1989; Unger, 1994; Hamed *et al.*, 2010) have stated similar effects of mulches on protecting the surface and improving the structure and moisture status of the soil. Despite the good performance of mulching technique, the porous soil under the mulch can enhance evaporation losses from surface layers during the prolonged dry periods. Similar suggestions were also reported by Phipps and Cochrane (1977) and Gicheru et al. (2006). Meanwhile, the bunded plots (T_4 and T_5) only accumulated the runoff water and eroded soil particles immediately above the bunds, thus retained more rain water at the lowest point against the bund arms. Earth budding was superior against mulching for moisture storage at 0-30 cm depth during dry periods. Furthermore, the superiority of T_4 over T_5 was attributed to its greater impounded area (8.3 m^2 as compared to 4.1 m^2 for T_5). This was reflected better, but non-significant in plant performance. The low moisture content under T_0 could be attributed to the severe competitive effect of the crop roots on the available soil water (Hassan *et al.*, 2012). Moreover, interception by canopy cover could prevent light rains from wetting the soil or contributing to plant growth. These inferences are in consistence with what has been stated by Schwab et al. (1981) in that interception by dense vegetative covers commonly amounts to 25% of the annual precipitation.

The influence of the WHTs on soil structure and water conservation was reflected by the significant variation in growth and yield attributes of the tested plants. On the other hand, the non-significant effect of the techniques on some of the plant variables in the second growing season might often be due to the frequent rainfall and ample soil moisture in all techniques. The main reasons for the superiority of mulching and earth bunding on all plant variables could be the adequate initial available soil moisture, less soil surface level change, improved soil structure and fertility, and better aeration (Bayala *et al.*, 2012). Unger and Jones (1981) found that sorghum with high and medium water levels grew taller, yielded more and unused water more efficiently than sorghum with low water level at different growth stages.

Similar results were also reported on sorghum in USA (Doran et al., 1984) and on maize in Sudan (Haitham et al., 2009). In the first growing season, both groundnut and sorghum had suffered from the severe moisture stress conditions, during flowering, heading or pegging, which contributed greatly to vegetative growth and yield decreases. These findings were confirmed by Ahuja and Singh (1990), Ravindra *et al*. (1990) and Schmidt (1993) studies. Furthermore, the partial shading of the groundnut plant by the tall-growing sorghum cultivar during flowering and dry matter accumulation phases could affect peg formation and pod yield through reduction in photosynthesis and/or promoting aerial shoot elongation. This indicated that the relative advantages of intercropping were less under conditions of severe moisture stress. These results and inferences corroborate the findings of other researchers (Rao and Willey, 1980; Chinese *et al*., 1990) in various parts of the world, despite the low yields of intercropping and stone barrier treatment, relative to the other techniques, the net returns were found to be a higher combined yield of the former and the low cost of production of both techniques. These findings are inconsistent with the results of Ikeorgu and Odurukwe (1990).

***Conclusion*:** In conclusion, the mulching material and crop canopy reduced the formation of surface crusts and hence improved the water infiltration rate into the soil, although its usage is not promising under dryland farming conditions. The short growing early-maturing sorghum is more suitable for intercropping especially under short rainy seasons than the tall late-maturing sorghum. However, intercropping is beneficial under adverse situations of climate except at times of extreme water shortage. Because they are economically and technically feasible, particularly in small holdings, intercropping and stone barriers are proposed as the best combination for soil and water conservation and crop production.

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