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Effects of supplemental irrigation and water harvesting technique on productivity of rainfed sesame (*Sesamum indicum* L) crop in heavy clay soils

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ABSTRACT

Aim: The main aim of this study was to investigate the effects of supplemental irrigation and water harvesting technique on the productivity of rain-fed sesame *(Sesamum indicum L)* crop in Sudan's Butana-Heavy Clay Soil.

Materials and Methods: Effects of two in situ water harvesting techniques (tied ridges and conventional contour basin) and eight combinations of supplemental irrigation techniques at three growth stages of sesame crop (*Sesamum indicum* L.) were studied during two seasons in split-plot arrangement with randomized three replicated treatments in Butana-clay plain of Sudan. The crop phenological stages were from emergence to flowering (initiation and vegetative), flowering and heading maturity, and ripening. The irrigation treatments included supplementary irrigation in each growth stage or a combination of two and three growth stages, full irrigation, and the without irrigation (rain-fed) treatments.

Results: The results of statistical analysis of data collected during each one of the studied years and their combination indicated that the productivity of rain-grown crops was reduced whenever a deficit in water supply occurs due to bad distribution of rainfall during any crop growth stage. Supplementary irrigation can save the crop from complete failure in any dry year, and improve crop productivity. No significant differences between basins and furrows and they store a limited amount of water in the soil. The storage of the harvested water in the pond to be used when water shortage occurs always results in significant improvement in crop productivity.

Conclusion: It was concluded that Supplementary irrigation during the first crop growth stage or its combination with other stages results in significantly pronounced improvements in all aspects of crop productivity.

Keywords: Rain-fed farming, Water harvesting; Supplemental irrigation; Plant growth stages; Crop productivity.

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Introduction

Sesame is a drought-tolerant crop therefore it is mainly grown as a dryland crop especially in central rain lands of the Sudan, where crop sowing time is dependent upon the availability of moisture from rains. Sesame yield is highly variable depending upon the growing environment, tillage practices, and availability of water (Ahmed, 1998, El Nadi, 1969, El Amin, 1990). Changes in climate patterns, in particular, rainfall, combined with a fast increase in population growth resulted in increased flood demand for humans and animals in dry-prone areas. As such, rainfall cultivation is considered the most vulnerable human habitat (IFAD, 2010), FAO), (2007), Omer, 1989).

In Butana lands in east Sudan, most of the rains fall from July to September with only occasional rains in June and October. Water supply is often the most critical factor limiting crop growth and yield in rain-fed areas and the most expensive input of irrigated crops (Ahmed, 1998, Erkan, et al, 2007). Due to the high risks of frequent, temporary, and spatially changing rainfall calling for developing a method of rainfall prediction as pre-requisite to develop coping measures ahead. Notably, understanding the risks associated with crop cultivation in rain-fed areas is essential to finding solutions for improving productivity in dry areas especially during adverse weather conditions. Radwan et al (2012) reported that even the permanently irrigated agricultural sector is largely affected adversely by climate change. Oweis and Hachum, (2014) claim that successful implementation of WH practices requires significant knowledge input from hydrology, agronomy, and sociology. Identification of low-cost methods for assessing the potential of WH are needed and they are of greatest interest to stakeholders and investment agencies. The decision-making process concerning the best method applicable in particular environmental and geophysical conditions depends on the kind of crop to be grown and prevalent socio-economic and cultural factors. Water harvested needs to be stored to supplement crops at the time of water shortage and the most critical crop growth stage (Critchley, and Siegert, 1991). The knowledge of when to apply supplemental irrigation and the selection of the most efficient and economic water harvesting technique is crucial for improving crop productivity. Water harvesting is reported as one of the most effective coping strategies that farmer deploys in case of climate shocks and drought spells. However, water harvesting is classified into micro, macro, and runoff farming systems. The selection of the coping technique to maintain high crop productivity in the dry-prone areas is much needed. Traditionally, farmers intuitively employ closed disked basins as micro-water harvesting techniques in rain-fed areas and open-ended furrows in irrigated areas to protect crops from water logging. The actual impacts of each in improving crop productivity are not certain (Ibrahim, 2010). The soils of central Sudan are heavy clays that form deep cracks when dry and swell on wetting to the extent that internal drainage is negligible. It is well documented in the literature that supply or withholding water at particular phases of crop development may affect a crop yield (Loggale, 2018; Erkan, et al, 2007), which is clearly of economic and water conservation importance. This requires harvesting and storing excess rainwater, directly on or in the soil or farm ponds, to be used during dry periods.

Sesame is grown as a rain-fed crop in Sudan. In Sudan, Sesame is a very important oil crop, both for local consumption and export. Sesame is one of the major foreign currency earners, after cotton, for Sudan (Nimir, 2002, Osman, 1985). Sudan occupies the third rank as world producer, nevertheless, it is considered as the first world exporter of a Sesame seed. The annual production of Sudan amounts to 13.5% of the total world production and about 50% of African production (FAO Sudan, 2016), Khidir, 1997). In Sudan, Sesame is grown as a rain-fed crop. The total area of production varies from one year to another, mainly due to fluctuations in rainfall and prices (Osman, 1985; Mahmoud, 2007; Khidir, 1997). El Naim (2003) reported that 77% of the cultivated area lies in the three states, North Kordofan, Blue Nile, and Gadaref state. The total cultivated area of sesame in Sudan is about 1.5 million hectares (FAO, 2000). In the report on the annual crop and food supply assessment mission, Sudan (2016) claim that planted area for sesame was reduced from 3.26 million ha in 2014 and 2.75 million ha for the five-year average to 2.42 million ha the year 2016. The late arrival of planting rains in July, the normal planting time for sesame, forced some farmers to change to other crops. Sesame prices on the world market are not favorable at present also. The main problems limiting production and expansion of Sesame as pointed out by Mahmoud (2007) Khidir (1997); Osman (1985); Mahmoud,2007); Khidir (1997) are low yield potential of existing varieties; scarcity, and reliability of rainfall; limited use of certified seed by the Sesame growers, due to deficient marketing and farmers planting uncertified seeds; inadequate weed control; harvest problems mainly related to capsule dehiscence, labor shortage; the prevalence of various pest (e.g. sesame webworm; Antigastra catalaunalis). In Sudan, the volume of research related to Sesame crop water relations is relatively small in comparison with the other oilseed crops (El Naim, 2010). Against this background, the objectives of this study were to investigate the effects of supplemental irrigation and water harvesting technique on the productivity of rain-fed sesame *(Sesamum indicum L)* crop in Sudan's Butana-Heavy Clay Soil.

Materials and Methods

The experiment was conducted in clay soil, at a farm at the Seleit North Agricultural Project in Butana, Sudan during the 20018/2019 and 2019/2020 seasons. The Seleit agricultural scheme lies within the Seleit area that constitutes the western part of Butana clay plain in central Sudan. It is located between 32°31\`- 33° 00\` E and 15° 45\`- 16° 00\` N, and has an area of 1,150 km². The experimental area lies in a flat plain with some scattered soil outcrops. It is of a semi-arid climate (average annual rainfall 120 mm), with sparse vegetation. About 80% of the area is dominated by the rangeland with little cultivation near the Nile and in the courses of the Wadis (ephemeral seasonal streams). The main Wadis of the region are El Kangar, El Seleit, El Jaili, and El Kabbashi (Ibrahim, 1987; Mahmud et al., 2007). The soil of the area was heavy montimorillinitic clay with the following soil characteristics:

Table1.0: The Soil characteristics

Soil Character	Value	Soil Character	Value
Salts (%)	0.06	C (%)	0.46
Na value	15.67	Clay (%)	66.67
P2O5 (ppm)	62	Exch. Ca (mg/100gm)	20
N (ppm)	481	PH glass electrode (1:5)	8.17
Nitrate (ppm in fresh soil)		4.68	

The crop phenological stages are from emergence to flowering (initiation and vegetative), flowering and heading maturity, and ripening. The supplemental irrigation treatments consisted of eight levels. The arrangement of supplementary irrigation treatments is based on that used by Farah (1983) in Kenana Research Station for Sorghum crop. The irrigation treatments are:1- irrigated in the three stages (full irrigation), 2- irrigated in stage one, two and not irrigated at stage three, 3- irrigated at stage one, not irrigated at stage two & irrigated at stage three, 4-irrigated in stage one not irrigated at stage two, and not irrigated at stage three, 5- not irrigated at stage one irrigated at stage two and irrigated at stage three 6- not irrigated at stage one, irrigated at stage two, and not irrigated at stage three, 7- not irrigated at stage one, not irrigated at stage two, and irrigated at stage three,8- not irrigated at stage one, not irrigated at stage two, and not irrigated at stage three, (Rainfed).

The two WH treatments used were contour flatbed basins (10 x 15m) and tied furrows (1.5 m length and 0.8 m apart). The furrow pattern comprised two elements: the ridge acts as planting area and as the runoff area, and the furrow area as the infiltration and as storage basin (each with dual functions). In a flat basin, the storage area is the whole area for the whole plants, while in tied furrows the storage area is nearby the limited number of plants. The four borders of each plot were raised to 60 cm above the soil surface. The layout of the experiment was a split-plot design with three replicates. The main plots were assigned for water harvesting (WH), and the subplot for supplemental irrigation. The recommended sesame, varieties of Khidir was used. The crop was sown manually at a spacing of 15 cm apart on ridges of 80 cm spacing on flat in basins in July 2018 and 2019. Manual weeding was carried out three times during each growing season.

The experiment plots were 10x15 meters. Watering was controlled and measured by an electric pump of a calibrated discharged (276.5 liters per minute) from erected farm pond "Hafir". The time required to apply a certain volume of water for each subplot was determined with the help of a stopwatch (El Nadi, 1969; El Naim, 2003). All experimental plots received similar amounts of water for the first 25-30 days after sowing to establish the plants. In each subplot, the three inner tied ridges and the inner 7 x 6 m in each basin were used for determining yield attributes: number of capsules per plant, number of seeds per capsule, 1000 seed weight (g), seed yield per plant (g) and seed yield (t/ha). The harvest index was determined as follows: Harvest index "Economical yield (Seeds yield (gm/plant)"; Biological yield (Shoot dry weight) (gm), Number of seeds/capsule, Number of capsules/plant, seed yield /plant (gm), 1000-seed weight (gm), and harvest index (%).

A split-plot design was used with the two WH techniques allocated to main plots, and the irrigation treatments to sub-plots which were randomized in three blocks. Each subplot was 10 x 15 m. Analysis of variance appropriate for the split-plot design was applied according to Gomez and Gomez. The mean separation was done using Duncan Multiple Range Test for different characters (Gomez, and Gomez, 1984). The chronological events of cultural operations during the two seasons of the study were depicted.

Results and Discussion

Yield Productivity Parameters:

Seed Yield (t/ha): In 2018 and 2019 differences among seed yield of water harvesting treatments (WH) were very highly significant ($P < 0.001$) from one another. In 2018 Tied furrow mean seed yield (2.987 t/ha) out yielded basin system (2.258 t/ha) with 31% more seed yield. While in 2019 the Least Significant Difference (LSD) test shows that seed yield in the Basin system (2.45 t/ha) significantly out yielded tied furrows (2.39 t/ha) by 2.5% more.

The mean seed yield (t/ha) for supplementary irrigation treatments for 2018 & 2019 was given (Table 2). It was shown in the table that there are significant differences in the mean yield for supplementary irrigation treatments in season 2018. The mean of full irrigation treatments (3.3 t/ha) improved seed yield over rain-fed treatments (1.9 t/ha) by1.4 t/ha. Seed yield due to Supplementary irrigation during stage one results in mean seed yield higher than that obtained by irrigating during stage 2 which in turn is higher than the yield due to irrigating in stage three. The mean seed yield in descending order obtained due to supplementary irrigation at combined stages is stage 1&2 >1&3> 2&3. Lack of supplementary irrigation in stage one is of significant influence on obtained seed yield. For the year 2019 seed yield obtained with full irrigation (3.1 t/ha) is more than that obtained with rain-fed treatments (1.8 t/ha). However, seed yields during 2019 are less than that obtained in the year 2018, and such difference may be attributed to the higher rainfall in the year 2018. The (LSD) test for seed yield for supplementary irrigation treatment in2019 shows that treatments can be ranked into six different groups (Table 2).

Table 2: Mean Seed yield (t/ha) for supplementary irrigation treatments for 2018 & 2019

Treatment	Irrigation Stage	The year 2019		The year 2019	
		Seed Yield (t/ha)	LSD-Homogeneous groups	Seed Yield (t/ha)	LSD-Homoge-neous groups
1	full Irrigation	3.3	A	3.1	A
2	1&2	3.1	B	2.8	B
3	1&3	2.9	C	2.7	C
4	1	2.8	D	2.4	D
5	2&3	2.6	E	2.5	DE
6	2	2.5	F	2.3	E
7	3	2.0	G	1.8	F
8	(Rain fed)	1.9	G	1.8	F

To ascertain improvements of using supplementary irrigation at the three growth stages over rain-fed watering Dunnett's multiple range tests using treatment 8 as control (no supplementary irrigation) (Table 3) indicated that differences in seed yield with the highest improvement were achieved by combined supplementary irrigation during stages 1 and 2 (3.1 t/ ha) followed by combined stages of 1 and 3 (2.9 t/ha). This result is in agreement with Farah, (1983) in his study of the effects of supplementary irrigation at different growth stages of the Sorghum crops.

Table 3: Two-sided Dunnett's multiple comparisons of irrigation treatment means for 2018

Irrigation Treatment	Lower Mean	Upper Bound	Difference	Bound
1	3.317	1.3190	1.4167*	1.5143
2	3.050	1.0524	1.1500*	1.2476
3	2.900	0.9024	1.0000*	1.0976
4	2.750	0.7524	0.8500*	0.9476
5	2.633	0.6357	0.7333*	0.8310
6	2.483	0.4857	0.5833*	0.6810
7	1.950	-0.0476	0.0500	0.1476
8	1.900	Control		
Alpha =0.05	SE = 0.035	Critical comparison value =0.0976		

The results of two-sided Dunkens Multiple Comparison of seed yield with full irrigation as a control for the year 2019 are depicted in table 4.0. The table indicates that full irrigation improved seed yield significantly and the contribution of supplemental irrigation in individual growth stage or a combination of them in improving seed yield can be ranked in descending order as 1&2>1&3>1&3>1>2>3>rain fed. These results indicate the importance of giving supplementary irrigation at stage one as an individual stage or in combination with other stages (with 2 is better than with 3), and such results confirm the results obtained in season one.

The combined effect of the two seasons on seed yield gave results typical to that of the year 2018. This can be visualized from figure 1.0. The figure indicates the superiority of tied furrows over the basin and the rank of the significant contribution of supplemental irrigation at growth stages in descending manner in the order of 1 (all stages irrigation)> 1&2>1&3>1>2&3>2>3>rain fed.

A number of Seeds /Capsule: The Tied furrow WH treatment gave a higher mean number of seeds per capsule than the basin method, but these differences were not significant in the year 2018 or their interaction with supplementary irrigation treatments.

Supplementary irrigation treatments in the year 2018 show the significant difference and using LSD these treatments can be grouped into 8 distinct groups (Table 5). The two-sided Dunken Multiple Comparison of seed yield with full irrigation as a control for the year 2018 and percentage improvements over rain-fed irrigated fields is depicted (Fig 1). The table reveals that a higher improvement in a number of seeds per capsule can be obtained by full irrigation followed by combined irrigation during stages 2 and 3 together, while the least improvement can be obtained by supplementary irrigation in stage one alone.

Table 4.0: Two-sided Dunnett's Multiple Comparison of seed yield with full irrigation as control and with % improvement over rainfed treatment

Irrigation Treatment	Lower Mean	Upper Bound	Difference	Bound	% improvement over Rainfed
1 = (full irrigation)	3.1167	Control			78
2 - (At Stage 1 &2)	2.8333	-0.432	-0.2833*	-0.1347	62
3 = (At Stage 1 &3)	2.6833	-0.582	-0.4333*	-0.2847	53
4 = (At Stage 1)	2.3667	-0.8986	-0.7500*	-0.6014	35
5 = (At Stage2 &3)	2.4500	-0.8153	-0.6667*	-0.518	40
6 = (At Stage 2)	2.3333	-0.932	-0.7833*	-0.6347	33
7 = (At Stage 3)	1.8167	-1.4486	-1.3000*	-1.1514	4
8 = (Rain fed)	1.7500	-1.5153	-1.3667*	-1.218	Control

Table 5: Two-sided Dunnett's Multiple Comparison of number of seed per capsule with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for the year 2018

2018 Irrigation	Stages	Mean	Lower Bound	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	58.333	Control		75	A
2	1&2	47.150	-11.914	-11.183*	41	B
3	1&3	52.033	-7.031	-6.300*	56	C
4	1	37.917	-21.147	-20.417*	13	D
5	2&3	56.833	-2.231	-1.500*	70	E
6	2	46.483	-12.581	-11.850*	39	F
7	3	48.567	-10.497	-9.767*	45	G
8	Rain fed	33.417	-25.647	-24.917*	Rainfed	H

Table 6.0: Two-sided Dunnett's Multiple Comparison of a number of seed per capsule with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for the year 2019.

2019 Irrigation	Stages	Mean	Lower Bound	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	49.700			75	A
2	1&2	37.250	-20.960	-12.450	41	B
3	1&3	34.383	-23.827	-15.317	56	B
4	1	26.433	-31.777	-23.267	13	B
5	2&3	36.867	-21.344	-12.833	70	BC
6	2	31.600	-26.610	-18.100	39	BC
7	3	32.350	-25.860	-17.350	45	CD
8	Rain fed	21.583	-36.627	-28.117	Rainfed	D

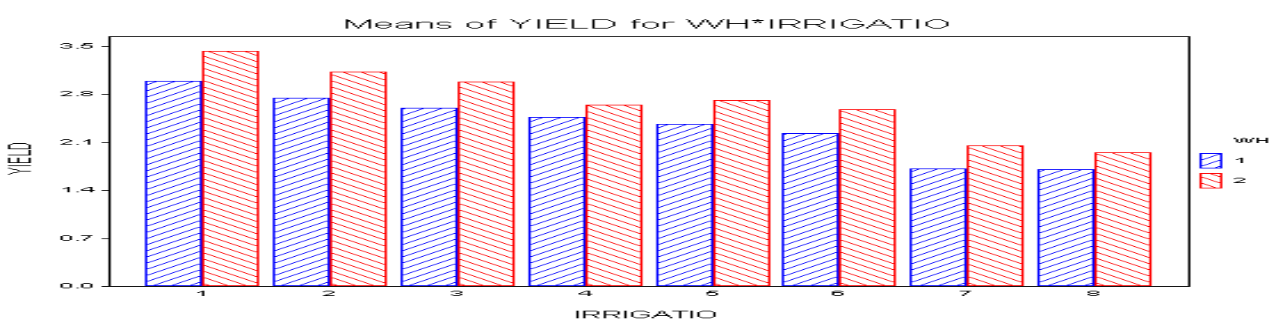

Fig. 1: The combined effect of the two seasons on seed yield (t/ha) due to irrigation and water harvesting treatments

In season 2019 there were significant differences in both WH and irrigation treatments and their interaction in the number of seeds per capsule. LSD –test indicated that WH treatments are homogenous but irrigation treatment can be grouped into the 4-significant groups (Table 6). Supplementary irrigation results in improving a number of seeds per capsule with higher improvements over rain-fed watering are reached with supplementary irrigation during stages 2 and 3 in combination.

Statistical analysis of combining data of a number of seeds per capsule for the year 2018 & 2019 is exhibited in table 7.0. The result shows that there is a significant difference in a number of seeds per capsule due to both WH and Supplementary irrigation treatments, while their interaction is not significant. Recall that the level of significance of the effect of interaction differs in the year 2018 and 2019. The differences as suggested by Farah (1983), who studied the effects of supplementary irrigation on rain-fed grown Sorghum in Kenana, are due to the variability of rainfall in the two different years. This result is in agreement. in combing the two years together the WH treatments can be grouped in one homogenous group as the case of the year 2018 and 2019, while supplementary irrigation can be classified statistically into distinct seven groups with supplemental irrigation at stages 2 and 3 together resulting in the highest improvement in a number of seed per capsule following full irrigation as similar to the same cases in the two years.

A number of Capsule / Plant: Statistical analysis for the data on a number of capsules per plant indicates no significant differences due to the effects of the WH system, while there are significant differences due to applying supplemental irrigation at different growth stages and their combination with WH systems. The grouping of WH systems by LSD results in a homogenous one group. For supplementary irrigation, LSD shows that Full irrigation is one group (A), while supplementary irrigation at stage 1 or its combination with other stages (i.e. stage: 1&2, 1&3) form one homogenous group (B). Stage 2 alone or in combination with stage 3 results in one group with low or no improvement in a number of capsules per plant over rain-fed treatments were observed (Table 8).

The analysis of data for the number of a number of capsules per plant for the year 2019 indicated that there were significant differences in WH techniques, the treatments of supplemental irrigation, and their interaction. Pair-wise comparison using LSD Analysis for WH systems shows that a number of capsule per plant for tied furrows is higher than that obtained by the basin system. For supplementary irrigation it is possible to identify five significant groups (Table 9). Contrast analysis for supplementary irrigation treatments for full irrigation shows that contribution of supplementary irrigation and their combination at the different stages were low. Such results may be a reflection of the impact of genetic characters of the variety rather than being affected by the availability of irrigation water.

Analysis of the data of the year 2018 and 2019 in combination is shown in table 11.0, and the obtained results are typical to the data for the investigated years and can be visualized (Fig. 2).

Table 7.0: Two-sided Dunnett's Multiple Comparison of a number of seed per capsule with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for combining data for the year 2018 & 2019.

2019 Irrigation	Stages	Mean	Lower Bound	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	54.017			96	A
2	1&2	42.20	-17.14	-11.817*	53	B
3	1&3	43.208	-16.134	-10.808*	57	BC
4	1	32.175	-27.167	-21.842*	17	CD
5	2&3	46.85	-12.492	-7.167*	70	CD
6	2	39.042	-20.301	-14.975*	42	D
7	3	40.458	-18.884	-13.558*	47	E
8	Rain fed	27.50	-31.84	-26.517*	0	F

Table 8: Two-sided Dunnett's Multiple Comparison of a number of seed per capsule with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for the year 2018.

2018 Irrigation	Stages	Mean	Lower Bound	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig.	91.0			56	A
2	1&2	63.6	-31.095	-31.095	9	B
3	1&3	63.8	-30.895	-30.895	9	B
4	1	63.1	-31.595	-31.595	8	B
5	2&3	56.2	-38.495	-38.495	-4	C
6	2	36.0	-58.695	-58.695	-38	CD
7	3	54.3	-40.445	-40.445	-7	D
8	Rain fed	58.3	-36.395	-36.395	0	E

Table 9: Two-sided Dunnett's Multiple Comparison of number of seed per capsule with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for the year 2019

2019 Irrigation	Stages	Mean	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	101.95	0.00	33	A
2	1&2	94.6	7.35	23	B
3	1&3	91.65	10.30	19	B
4	1	93.15	8.80	21	B
5	2&3	93.1	8.85	21	B
6	2	83.7	18.25	9	C
7	3	70.4	31.55	-8	D
8	Rain fed	76.9	25.05	0	F

Table 10: Two-sided Dunnett's Multiple Comparison of number of seed per capsule with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for combining data of the year 2018 and 2019

combination Irrigation	Stages	Mean	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	96.475		43	A
2	1&2	79.1	-27.861	17	B
3	1&3	77.725	-29.236	15	B
4	1	78.125	-28.836	16	B
5	2&3	74.65	-32.311	10	BC
6	2	59.85	-47.111	-11	CD
7	3	62.325	-44.636	-8	DE
8	Rain fed	67.6	-39.361	0	E

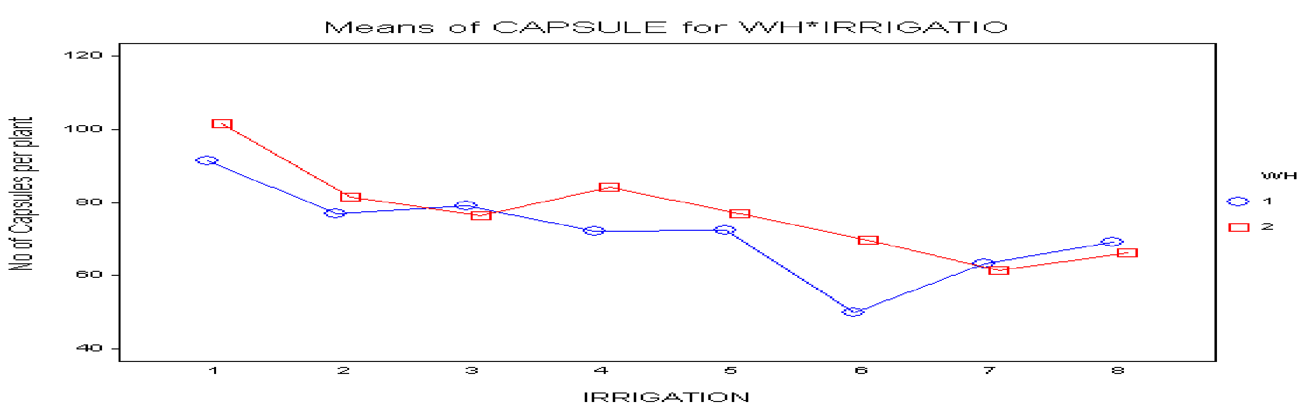

Fig. 2: The combined effect of the two seasons on the mean number of capsules per plant due to irrigation and water harvesting treatments

Seeds Yield / Plant: Analysis of the data collected for Seeds Yield / Plant indicates a significant difference in supplemental irrigation treatments for the years 2018, 2019 and their combined data. Differences in WH treatment is not significant during the year 2018 while significant effects were obtained in the year 2019 and combined data of the two years. The two-sided Dunnett's Multiple Comparison of a number of seed yield per plant with full irrigation as a control, with % improvement over rain, fed treatment, and classification into groups by LSD-test for combined data of the year 2018 and 2019 is depicted in table 11.0. The table shows that improvement in Seeds Yield / Plant is not significantly improved by supplementary irrigation at the different plant growth stages or even by full irrigation irrespective of the environmental condition of the study year.

1000 Seed weight: The field data collected for 1000-seed weight during the year 2018 shows that there was significant differences in WH, supplemental irrigation treatment, and their interaction.

Analysis of the data of season 2019 resulted in a similar trend as data of the year 2018 except for WH techniques which exhibit no significant differences between basins and tied ridging. Running LSD test for WH techniques in the year 2018 shows that basin irrigation resulted in significantly higher seed weight 1000-seed weight (2.91 gm) than tied furrows (2.67gm). As recorded, supplementary irrigation treatments can be grouped using the LSD test into 6 homogenous groups (Table 12). Regarding rainfall, water supply addition of supplemental irrigation at anyone or the combination of growth stages did not result in significant improvement in 1000 Seed weight. Likewise, the contribution of supplemental irrigation treatments in improving 1000-seed weight did not add much over rain-fed treatments.

The effect of WH techniques on 1000 Seed weight in the year 2019to was found to be of no significant effects and basin and furrows seed weight are the same. The eight supplementary irrigation treatments and their interaction with WH were found to have significant effects on seed weight. Two-sided Dunnett's Multiple Comparison of a number of seed yield per plant with full irrigation as a control, with % improvement over rain, fed treatment, and classification into groups by LSD-test for combined data of the year 2019 was depicted (Table 13). The table indicates a low percentage improvement in 1000 seed weight over rain-fed treatments.

Table 11: Two-sided Dunnett's Multiple Comparison of number of seed yield per plant with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for combined data of the year 2018 and 2019

combination Irrigation	Stages	Mean	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	32.142		43	A
2	1&2	26.367	-9.988	17	B
3	1&3	25.892	-10.463	15	B
4	1	26.042	-10.313	16	B
5	2&3	24.892	-11.463	10	BC
6	2	18.342	-18.013	-19	CD
7	3	20.767	-15.588	-8	DE
8	Rain fed	22.542	-13.813	0	E

Table 12: Two-sided Dunnett's Multiple Comparison of number of seed yield per plant with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for combined data of the year 2018

2018 Irrigation	Stages	Mean	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	2.8167		10	A
2	1&2	2.8667	0.05	12	B
3	1&3	2.7333	-0.0833*	6	C
4	1	2.6000	-0.2167*	1	D
5	2&3	2.9333	0.1167*	14	E
6	2	3.0167	0.2000*	18	E
7	3	2.7667	-0.05	8	F
8	Rain fed	2.5667	-0.2500*	0	F

Analysis of Combination of data for the year 2018 with 2019 (Table 14) indicated that supplementary irrigations are of significant impacts on seed weight and can be categorized into 6 groups, but their improvement over rainfed treatment was low. Similar to the year 2018 effects of WH techniques on seed weight are significant and the basin system (2.9 gm) out performed tied ridges (2.6gm).

Harvest Index (%): Effects of WH and supplementary irrigation and their interaction on harvest index were found to be significant for the years 2018 and 2019 and their combination. However, in all years basin irrigation resulted in a higher harvest index than tied furrows. As shown (Table 15) supplementary irrigation treatments are grouped into homogenous groups but their percentage increase in harvest index over rain-fed irrigation was low.

Table 13: Two-sided Dunnett's Multiple Comparison of number of seed yield per plant with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for combined data of the year 2019

2019 Irrigation	Stages	Mean	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	16.494		2	A
2	1&2	15.782	0.713	-3	A
3	1&3	15.696	0.798	-3	A
4	1	15.096	1.398	-7	A
5	2&3	16.299	0.195	1	A
6	2	16.559	-0.065	2	A
7	3	16.947	-0.453	5	A
8	Rain fed	16.193	0.301	0	A

Table 14: Two-sided Dunnett's Multiple Comparison of a number of seed yield per plant with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for combined data of the year 2018 and 2019.

combined Irrigation	Stages	Mean	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	2.7833		5	A
2	1&2	2.7583	-0.025	4	AB
3	1&3	2.6833	-0.1	2	AB
4	1	2.5667	-0.2167*	-3	B
5	2&3	2.825	0.0417	7	BC
6	2	2.8833	0.1	9	CD
7	3	2.8083	0.025	6	DE
8	Rain fed	2.6417	-0.1417*	0	E

Table 15: Two-sided Dunnett's Multiple Comparison of a number of seed yield per plant with full irrigation as a control, with % improvement over rainfed treatment and classification into groups by LSD-test for combined data of the year 2018 and 2019.

A. The year 2018

2018 Irrigation	Stages	Mean	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	18.733		14	A
2	1&2	18.233	-0.5	11	AB
3	1&3	18.117	-0.617	11	AB
4	1	17.767	-0.967	9	BC
5	2&3	17.783	-0.95	9	BC
6	2	17.3	-1.433*	6	CD
7	3	16.733	-2.000*	2	DE
8	Rain fed	16.367	-2.367*	0	E

B. The year 2019

2019 Irrigation	Stages	Mean	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	111.77		24	A
2	1&2	108.75	3.02	20	A
3	1&3	105.56	6.21	17	A
4	1	108.26	3.51	20	A
5	2&3	101.96	9.81	13	B
6	2	99.20	12.57	10	B
7	3	93.26	18.51	3	C
8	Rain fed	90.41	21.36	0	D

C. Combining the Year 2018 and 2019

combined Irrigation	Stages	Mean	Difference From full Irrig.	% improvement over Rainfed	Groups
1	Full Irrig	18.683		19	A
2	1&2	18.175	-0.508	16	B
3	1&3	17.858	-0.825	14	B
4	1	17.908	-0.775	14	BC
5	2&3	17.392	-1.292	11	CD
6	2	16.917	-1.767	8	D
7	3	16.142	-2.542	3	E
8	Rain fed	15.717	-2.967	0	E

Table16: Variability of crop productivity due to supplemental irrigation during single and combined crop growth stages

Stage Status	Irrigation Treatment	Seed yield (t/ha)	Seed yield/Plant (g)	Harvest Index %
Single Stage	4 = (At Stage 1)	2.3667	26.042	17.908
	6 = (At Stage 2)	2.3333	18.342	16.917
	7 = (At Stage 3)	1.8167	20.767	16.142
mean	mean	2.1722	21.7170	16.9890
Combined Stages	2 - (At Stage 1 &2)	2.8333	26.367	18.175
	3 = (At Stage 1 &3)	2.6833	25.892	17.858
	5 = (At Stage2 &3)	2.4500	24.892	17.392
	mean	2.6555	25.7170	17.8083
Reference (max)	1- Full Irrigation	3.1167	32.142	18.683
Reference (min)	8 = (Rain fed)	1.7500	22.542	15.717

Crop productivity Variation with Stages: Variation of crop productivity expressed by seed yield (t/ha), seed yield per plant (gm), and Harvest index (%) due to the application of supplementary irrigation in single crop growth stage or combination was depicted (Table 16).

From the table, it can be noted that: Full irrigation and increase in irrigation intensity results in highest productivity Supplementary irrigation in Combination of stages is better than irrigation in one single stage. Supplementary irrigation at Stage one is better than the other two stages if water is applied at a single or in combination. Several reports in the literature indicate that irrigation water shortage has great effects on the yield of crops when they occur during the boot through to the bloom stage (Here stage 1), whereas the least detrimental effects on crop productivity occur during the milk to soft dough stage (Cochran and Cox, 1957). It is apparent from the data of table 16.0 that water shortage during the first stage can influence significantly those during the second and the last period, especially during the dry spell. Cochran and Cox, (1957) and Farah, (1983) attributed the positive and dominance of the effects of supplemental irrigation in period one over other periods probably to induction of the time of floral initiation and seed setting, were short of moisture in the stage results in a decrease in the formed number of grains. Moreover, Eck and Mesick (1979) argue that adverse water conditions are likely to affect seed growth.

Conclusions

Statistical analysis of data collected during the studied years or their combination indicated that: Productivity of rain-grown crops was reduced whenever a deficit in water supply occurs due to bad distribution of rainfall during any crop growth stage. Supplementary irrigation can save the crop from complete failure in any dry year, and improve crop productivity. No significant differences between basin and furrows for both store limited amount of water above soil surface and storage of the harvested water to be used when water shortage occurs always result in significant improvement in crop productivity. Supplementary irrigation during the first stage or its combination with other stages results in significantly pronounced improvements in all aspects of crop productivity.

References

Ahmed MH (1998). Release of cultivar Khidir for production in high rainfall areas, (Southern Gadarif and Damazine) Sudan Journal of Agric. Research, 1(1): 89.

Ahmed MA (1998). A note on the performance of two sesame (Sesamum indicum L.) genotypes suggested for releases. Yield stability of sesame in the central rain lands of Sudan. Paper submitted to the variety release committee, Kenana Res. Station.

Critchley W and Siegert K (1991). Water Harvesting: a Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. AGL Miscellaneous Paper No. 17. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

El Amin AM (1990). Yield Response to Water Stress in Sesame (Sesamum indicum. L) M.sc. Thesis. Fac. Of Agric. The University of Khartoum.

El Nadi AH (1969). Efficiency of water use by irrigated wheat in the Sudan. Journal of Agricultural Science, Cambridge, 73: 261-266.

El Naim M, Ahmed F and Ahmed Mahmoud (2010). Effect of irrigation on consumptive use, water use efficiency, and crop coefficient of sesame (Sesamum indicum L.). Journal of Agricultural Extension and Rural Development, 2(4): 59-63.

Erkan B, Davut K, Mehmet S, Sinan G, Hilaj K, Yasar K and Irfan O (2007). Effect of Irrigation Method and Irrigation intervals on Yield and Some Yield Components of sesame growing in Semi-arid Area. Journal of Agronomy, 6(3): 439-443.

FAO Sudan (2016) Annual crop and food supply assessment mission, Sudan January (2016) Fedral Ministry of Agriculture and Forests Sudan Meteorological Authority, FAO Sudan, the World Food Programme (WFP) the Famine Early Warning Systems Network (FEWS NET), and USAID.

FAO (2007). Food and Agriculture Organization (FAO), (2007). Climate Change and Food Security: A Framework Document, FAO, Rome, Italy, 2007. Food and Agriculture Organization (FAO), Statistical Year.

Farah NM (1983) Effects of supplementary irrigation on rain-grown sorghum (Sorghum bicolor) in the Sudan. J. gric.Sci., Cmb.100.3233-327.

Gomez KA and Gomez AA (1984). Split plot design analysis. In: Statistical procedures for agricultural research. John Willey and Sons, New York.

Ibrahim A (1987). Hydrological Investigation of Seilitat Area, Thesis (M.Sc.), Wad Al Magbol Institute for Earth Science-Sudan.

Ibrahim MB (2010). Rainwater Harvesting in Drought-stricken Areas of Central Sudan. A Paper Presented to the Annual Meeting of the Association of American Geographers, April14-18, Washington D.C.

Loggale LB (2018)."Performance of Two Sesame Cultivars as Influenced by Supplemental Irrigation at Abu Naama." IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS) 11(9): 06-11.

Mahmud Wifag Hassan, Roefhrig Jackson and Ganawa Etayeb (2007). Assessing the potential of floodwater harvesting in Seleit Area Wadis, Sudan - using remote sensing and GIS. University of Kassel-Witzenhausen and University of Göttingen, October 9-11, 2007 Conference on International Agricultural Research for Development.

Nimir ESN (2002). Effect of water stress applied at different stages of growth on the performance of two sesame (*Sesamum indicum* L.) cultivars. M.Sc. Thesis. Fac. of Agric. University of Khartoum.

Omer SA (1989). Some Aspects of Socio-economic and Environmental Change in Simsim Area, The case of Sudanese-Canadian project.

Osman HE (1985). Sesame growing in the Sudan .In sesame and safflower: Status and potential. F.A.O. plant production and protection paper. pp: 66.

Oweis T and Hachum A (2014). Water Harvesting for Improved Rain fed Agriculture in the Dry Environments. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.

Radwan Al-Weshah and Fayez Abdullah (2012). Climate change risk management on hydrology of wadi systems in the Arab Region: International Conference on Earth Science & Climate Change August 21-22, 2012 Hilton Chicago/Northbrook, USA

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