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Using micro-water harvesting techniques and water management methods for mitigating environmental degradation in rainfed Sesame production in Butana drylands, Sudan

[1]Hassan IM, [2]Hussein A, [1]Abbas OM and [3]Khalid OB

[1]Department of Agricultural Engineering; Collage of Agricultural Studies; Sudan University of Science and Technology; [2]Ministry of Agriculture Khartoum State; [3]Department of Agricultural Extension and Rural Development, College of Agricultural Studies, Sudan University of Science and Technology, Sudan

Corresponding author: hassantal@gmail.com

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ABSTRACT

Aim: The main objective of this study was to compare the performance of frequently recommended three micro-harvesting land surface forming techniques (broad base basin- furrows, open-ended furrows, tied furrows), and three harvested rainwater conservation practices (fully irrigated, rain fed, and supplemental irrigation).

Materials and Methods: A farm pond and a small pump were used to harvest rainwater during the rainy season, and stored water was conveyed to cropland as supplemental irrigation (SI). Data collected includes sesame crop yields (Kg/ha), plant height (m), number of capsules per plant, and water use efficiency.

Results: The result revealed that there were statistically significant differences (p=0.01) between water management practices, and plant height, number of capsules per plant, and seed yield, and the highest seed yield was obtained from fully-irrigated treatment). The response of Sesame number of capsules per plant to both water management practices and water harvesting techniques is highly significant, while the interaction between these treatments is non-significant, and broad based furrows fully irrigated plots recorded the highest number of capsules per plant. Full irrigation results in maximum crop height with water harvesting that do not pond water in localized area (Broad based Furrow in basins and conventional furrows).

Conclusion: It was concluded that under the case of low water supply both broad based furrow and tied furrows store water over the soil surface resulting in improved crop yield. The conventional furrow application technique for irrigated agriculture and brad based for rain fed agriculture.

Keywords: Tied-furrows; broad base furrows, open-ended furrows; supplemental irrigation; rain fed agriculture.

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Introduction

In Butana dry land prolonged Drought conditions resulting from low rainfall with varying and non-uniform spatial and time distribution, coupled with high evaporation and evapotranspiration (Kassas, 1995), can lead to provoked land degradation due to vegetation cover loss, reduced productivity of food crops and soil erosion, caused by human activity (Requier Desjardins et al., 2011 and Wickens, 1997). As a result, the environmental and economical potential of the region started to decline (Reynolds, 2001; Kassas, 1995) heading to a nonreversible point; i.e. desertification, if no mitigation measures are put into action (Wickens, 1997 and Kassas, 1995).

People realized the problem and initially implemented water harvesting farm ponds for domestic uses and newly started to establish micro-water harvesting techniques for improving crop production for food security and poverty reduction reasons. These include a variety of infield crop management practices that range from primary and secondary tillage practices for crop seedbed preparations, and weed management through micro-harvesting land surface forming practices. Such as basins, furrows, tied furrows, and land fallowing. However, the designs and impacts of these micro-harvesting techniques are at their infant stage. Abdelhadi et al., (2002) stated that simple water harvesting techniques were often overlooked as an attractive option to increase rainfed crops and help the local people attain some degree of food security, and reduce their mass immigration towards large cities (Laflen and Colvin, 1981).

Elramlawi et al (2009) recommended adopting in situ water harvesting technique from comparing four soil surface formations (furrows, tied furrows, wide level disc, and sowing on flat non-tilled soil surface) for two consecutive rainy seasons, 2004/05 and 2005/06, on yield and yield components of maize in the North of Gadaref State. A split-plot design study was conducted by Babikir et al (2017) using four in-situ water harvesting techniques (two tied- ridging spaced at 1 m, and 2 m, and two furrow-ridge with ratios of 1:1 and 2:1), and the conventional tillage practice to evaluate the effect of water harvesting techniques and three chisel plow depth (20,25,30 cm)on yield and yield components of sorghum (Sorghum bicolor L.) under the dryland farming of Gadaref State, Sudan during three consecutive seasons (2010/09, 2011/10 and 2012/11). The collected includes rainfall, and crop data including plant population(PP), plant height at flowering (PH), dry matter (DM), total grain yield (GY), water productivity (WP), and 1000 seeds weight (1000 SW). Their result showed no significant ($p>0.05$) difference between the situ water harvesting techniques and between the interaction of water harvesting techniques and chisel depth in the three seasons, while there was a significant improvement in crop productivity by the studied in situ water harvesting techniques over the wide level conventional tillage practice. Consequently, they recommend successfully use them to meet the water demand of sorghum in the North of Gadaref State, which suffers from intermittent and low rainfall.

From the results of two years' studies of ridge-furrow, and flat planting rainwater harvesting planting patterns with three supplemental irrigation amounts to improve dry matter (ADM), nitrogen nutrition index (NNI), radiation use efficiency (RUE), water use efficiency (WUE), and seed yield of winter oilseed rape (Brassica napus L.), Gu et al (2017) reported that rainwater harvesting technique lessens the effect of water deficits throughout all crop growth stages, but water shortage remains unavoidable during some stages of crop growth in arid and semiarid areas, and supplemental irrigation would still be needed to achieve higher production.

Ali et al (2019) studied the impacts of supplemental deficit irrigation strategy of using reduced quantities of water duty (75,37,18,0 mm), full irrigation (150,75, 37 mm), and three rainwater harvesting systems (flat planting with border irrigation, plastic-covered ridge, and furrow) for improving grain filling, economic return, and production in winter wheat. The results showed that the ridge furrow system with border irrigation has significantly increased soil water storage and water use efficiency. He recommended using the reduced 75 mm treatment for it resulted in significantly greater soil water storage, improved biomass per plant, leaf area index, net income for farmers, reduced evapotranspiration, decreasing irrigation water usage, and increasing the effective consumption of precipitation.

Johnson et al (2021) studied the responses of growth, and grain yield of dryland sorghum and soil moisture storage with an infield six treatments of rainwater harvesting - tillage methods (flatbed, basin tillage method, Open-end tied furrows with planting on furrows, Open-end tied furrows with planting in furrows, Closed-end tied furrows with planting on furrows, and Closed-end tied furrows with planting in furrows), in two-seasons, in Zimbabwe. The study result indicates that the deep basin tillage method significantly increased both sorghum plant biometric growth parameters, and the soil moisture content above that in conventional tillage plots, in the furrows, and furrows of open and closed-end tied furrows. Open-end tied furrows with planting on furrows, Open-end tied furrows with planting in furrows introduces homogeneous soil water build-ups in furrows and furrows as those observed in tied end furrows with closed ends. As a consequence, biometric growth parameters of sorghum are not altered by substituting open with closed-end tied furrows.

Sesame seed has a long history of use for its oil as well as for other food products such as bread and bakery items. Approximately 70% of worldwide seed production is processed into oil and meal (Morris, 2002), as cited by USDA plant guide. Growing drought-tolerant crops as a useful strategy in many situations and efficient use of limited water are considered (English et al., 1990). Sesame is a very important crop with drought-resistant characteristics and suitable for cultivation in semiarid areas than other crops. In sesame, like other crops, the grain filling period is of great importance in determining productivity.

Although the grain filling period is influenced by plant genetics, environmental stresses such as drought can cause yield loss (Frederick et al, 1991). According to El Mahdi and El-Amin (2008) Sesame (Sesamum indicum L.) is the most important oilseed crop in Sudan; it is grown mainly in two farming systems, either traditionally or mechanized. The first is under traditional rainfed (350-800 mm) on the dunes of Kordofan and Darfur States, which contributes about 28% of the sesame production. The second is the mechanized rainfed system (400-800 mm) in Gedarif and Damazine clay plains and Northern Upper Nile and contributes about 53% of the sesame. Naba et al (2020) evaluated the effect of in-situ rainwater harvesting techniques (Targa, Zai, Tie ridge and Control) on rain fed maize production in moisture stress areas of humbo woreda, wolaita zone in Ethiopia. He described these in-situ rainwater harvesting techniques as: with maize planting Tied ridge: (ridges or furrows are blocked with earth ties with intervals or furrow disking) Planting pit/Zai (dug holes 16 cm depth, spaced at 40 cm and between row 75 cm filled with urea and decomposed crop residue), Targa (rectangular basin built from soil or crop residue along contour lines spaced 1.5 m apart and tied at 1.43 m interval by earth ridges).He concluded that the soil moisture, grain yield and biomass for the Targa were consistently higher when compared to the control or the other techniques.

The main objective of this study was to compare the performance of frequently recommended three micro-harvesting land surface forming techniques (broad base basin-furrows, open-ended furrows, tied furrows), and three harvested rainwater conservation practices (fully irrigated, rain fed, and supplemental irrigation)**.**

Materials and Methods

Treatments and Experimental design: The study was made in Seleit Scheme as part of Wadi El Seleit (344 km^2) in the Butana area. Nine treatments of water harvesting techniques for modification of soil surface formation (Conventional open furrows "80 cm spacing", tied furrows " 1.2 m lengths", and closed-end broad base ridge in a basin "1.2 m spacing"), and three soil moisture management methods (fully irrigation, rainfed, and supplemental irrigation) were arranged in a completely randomized design with three replicates in the two growing seasons (2018/2019, and 2019/2020). The soil of the experimental site is predominantly Vertisols, deep dark-colored clays of montmorillonite mineralogical origin (clay content is 57.6 %, Sand 21.1%, Silt 21.3%) characterized by high water holding capacity, low infiltration rate (2-3 mm/hr), low nitrogen content (0.212%), low organic matter (1.4%), ECe (0.37), and high pH (8.7). the soil is sticky on wetting, and crack on drying. The measured soil field capacity is 53.6 % and wilting point is 31.6%.

Data Collections: The plot area was 1050 m2 and a buffer zone was left between plots and around the experiment area to facilitate crop management operations. A (10x10 m) grid map was prepared for the experimental area using surveying equipment. A mild slope of about 0.05% dominates the area. The seedbed preparation in the experimental area was made by disc plow, disc harrow, and scraper for land planning. A shovel tire machine was used to construct a farm pond and water conveyance channel. The rain harvested water was used only for plots with supplementary irrigation. For fully irrigated plots water from the start of sowing till harvest is conveyed via a field channel (A/XX) from the Seleit Project Minor Canal. Massy Ferguson tractor (75 HP) was used for making furrows and in-field internal channels, bunds, and external borders. The conventional open-ended furrows were 80 cm spaced and 25 cm in depth. The broad base furrows were 120 cm spaced with a furrow top of 40 cm and a depth of 25 cm. The ties are made manually and 1.2m spaced along the furrows in form of spill using a sac filled with mud and with a height of 20 cm from furrow bottom to pond and store irrigation water and at the same time allow water to enter the furrow pond (1.2 m length), and excess water to spill out of it. Flow measurements into each plot were measured using a Vane Flow Meter and calibrated 3 inch - pump following the method described by (Ahmed and Mahmoud, 2010). The farm pond and the pump were used to harvest rainwater during the rainy season, and the stored water was conveyed to cropland as supplemental irrigation (SI). Irrigations were done on a decadal basis, considering the required net depth (ND) of replacement as (ND = ETc = ETo x Kc). Using depletion level of 0.6 the fully-irrigated plots received 175 mm of water per irrigation to bring the soil to field capacity, according while supplementary treatments received two irrigation each (88 mm), and applied at the second half of pod-setting and at seed filling period. Surface runoff is prevented by constructing field border dykes in all treatments except those for conventional free-draining furrows. Deep percolation is neglected because heavy soil restricts water percolation to deep layers (Ahmed and Mahmoud, 2010). The estimated evapotranspiration (ETo) was calculated using the Penman-Monteith method (Allen et al., 1998). Crop coefficients (factors) and yield response factors were taken from (Ahmed and Mahmoud, 2010, and Allen et al., 1998).). Climatological data were obtained from Shambat and Khartoum Airport Meteorological Station. Crop coefficients (Kc) were taken as 0.35, 0.73, 1.1, 0.25 for the lengths of growth stages (initial, vegetative growth, intermediate flowering stage, and maturation fruiting stage) 20,30,40,20 days respectively. Management allowable deficit (Mad) is taken as 0.6, and crop response factor of (ky) as 0.77 according to Allen et al., (1998).

Sesame crop (variety Khidir) was sown manually at a spacing of 15 cm apart on ridges in late July (27 of July 2018 and 2019) after rainwater fills the cracks. Crop cultural practices are made following the recommendations of the Agricultural Research Corporation. All treatments were subjected to a basal fertilizer application of 80 kg ha−1 of compound D fertilizer (10% N; 20% P_2O_5;10% K_2O; and 6.5% S). At five weeks after planting, the crop in all treatments was subjected to a top dressing application of ammonium nitrate fertilizer (34.5% N) at 200 kg ha−1. During the growing season, all plots were weeded manually at three and six weeks after sowing.

The observations were recorded on plant height, number of capsules per plant, and yield. Measurements of plant height and number of capsules/ plant were carried out on five plants randomly selected. At harvest, two rows were harvested each six meters long to determine the seed yield in kg/ha. Finally, statistical analysis was performed for separate seasons and pooled data of the two seasons.

The water use efficiency (WUE - kg m^3) was determined, according to Allen et al. (2006), by the relation between the sesame seeds yield (Y - kg ha-1) and the volume of water (V - m 3 ha-1) applied to each irrigation treatment given to the crop, according to Equation{ WUE = Y/V } . The response factor to water stress (Ky) was estimated according to FAO-56 (Allen et al., 2006), by the ratio between the relative decrease of yield (RDY) (1 – Ya / Ym) and the relative decrease of irrigation (RDI) (1 – ETc / ETm), according to the Equation:

Ky = [(1 – Ya / Ym)] / [(1 – ETa / ETm)] ------- (1)

Where, Ky is the response factor to water stress, defined as a decrease in yield (RDY) related to the decrease in the applied irrigation depth (RDI - dimensionless); Ya is the yield in a given applied irrigation depth (kg ha-1); Ym is the maximum yield (kg ha-1); Ya/Ym is the relative yield (dimensionless); (1 – Ya/Ym) is the decrease in the relative yield (RDY - dimensionless); ETa (Actual Crop Evapotranspiration), ETc is the applied irrigation depth that results in the yield Ya (mm); ETm is the maximum depth of applied irrigation (mm); Eta/ETm is the relative irrigation depth (dimensionless); (1 – ETa/ETm) is the relative decrease in the applied irrigation depth (RDI - dimensionless). The response factor to water deficit (Ky) was not statistically analyzed because it is native to the method and specific equation. The variables related to the components of production (number of capsules per plant, yield and seed oil content) and water use efficiency (WUE) were subjected to analysis of variance by the tests F and both 1 and 5% of probability using the statistical software. The response factor to water deficit (Ky) was not statistically analyzed because it is native to the method and specific equation. The weather data were also recorded (Table 1.0).

Data Analysis: The treatment effects on measured variables were analyzed using the GLM procedure of SAS Statistical Software Version 9.1 (Statistical Analysis System (SAS) Institute, 2002). Differences between treatment means were judged significant at $p \leq 0.05$ as determined by Fisher's protected least significant difference test.

Results and Discussion

Number of capsules per Sesame plant for water harvesting techniques and water management practices for season 2018, 2019 and combines seasons

the results of ANOVA analysis for the number of capsules per plant in years 2018, and 2019, and the combined effect of the two years (Table 3). It indicated that the response of Sesame number of capsules per plant to both water management practices and water harvesting techniques is highly significant, while the interaction between these treatment is non-significant in season 2018,

Table1: The climate data

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	16	31.6	33	199	10.4	21	5.63
February	16.6	33.1	26	242	10.7	23.2	6.91
March	19.8	37	22	251	10.4	24.6	8.12
April	23	40	21	190	10.6	25.8	7.91
May	26.2	41.8	24	207	9.9	24.7	8.43
June	27	41.5	30	207	9.8	24.2	8.31
July	25.6	38	45	259	8.6	22.5	7.74
August	24.7	36.1	56	233	8.6	22.6	6.66
September	25.5	38.3	44	199	9.2	22.9	7
October	25.1	39.2	32	147	10.1	22.8	6.49
November	21.1	35.7	31	181	10.6	21.6	6.25
December	16.8	32.2	35	199	10.4	20.3	5.6
Average	22.3	37	33	210	9.9	23	7.09

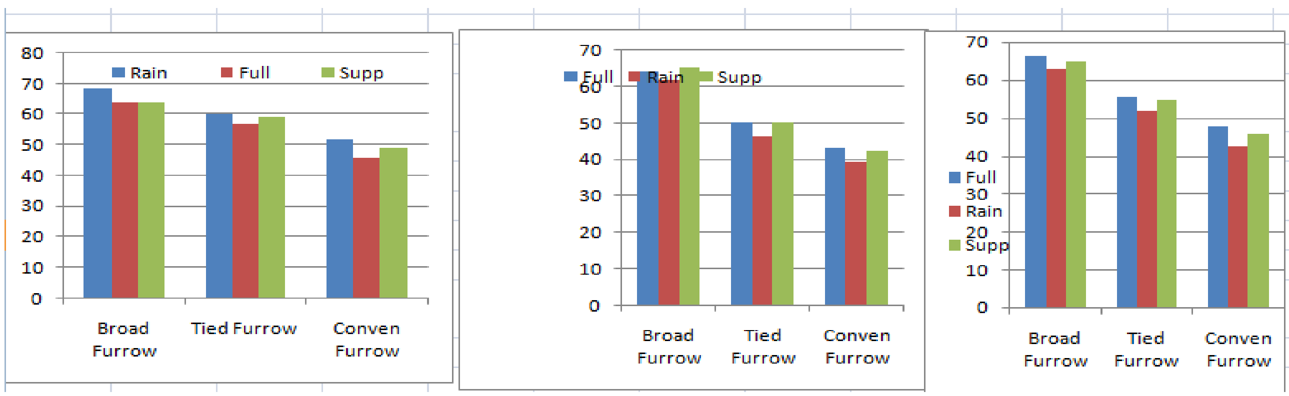

Fig. 1: Number of capsules per Sesame plant for water harvesting techniques and water management practices for season 2018, 2019 and combines seasons

while there is slight significant difference in their cross interaction and in watering management practices in the second season. During both seasons the broad based furrows fully irrigated plots recorded the highest number of capsules per plant (Fig. 1).

All water harvesting techniques high number of capsules per plant while rain fed resulted in lower values. This indicates that is plant character was a direct function of amount of applied water regime.

Effect of water harvesting techniques and water management practices on plant height (cm) for season 2018, 2019 and combines seasons: The data of mean values of Sesame plant height for water harvesting techniques and water management practices for season 2018, 2019 and combined seasons (Fig. 2) indicated that the maximum Height in first season is obtained by Broad based Furrow with full irrigation. For second season and combined effect the minimum height is obtained by conventional furrows with full irrigation.

In the first season the differences in water harvesting techniques are not significant, but they are significant for water management. This results support the results obtained by number of capsule which indicate the influential effects of a mount of supplied water on the plant agronomic characteristics. (Table4). This results is confirmed by Loggale (2018) study in clay soil at Abu Naama who confirmed that " there were statistically significant differences (p=0.01) between moisture regimes and plant height, number of capsules per plant, and seed yield, and the highest seed yield (832 Kg/ha) was obtained from fully-irrigated treatment). Teame et al (2021) reported inline results when they studied the Effect of land configuration ways (flat, ridge and furrow, and bed furrow.) on soil moisture and sesame seed yield and yield attributes in Ethiopia.

Variation of water harvesting techniques and water management practices on plant yield (Kg/ha) for season 2018, 2019 and combines seasons: It was showed that the Effect of water harvesting techniques and water management practices on crop yield (Kg/ha) for season 2018, 2019 and combination of seasons (Table 5). It indicate that there is no significant difference in levels of factor B (water management practices), while there is significant differences due to water harvesting techniques and their crossing with moisture management practices (Naba et al , 2020).

As the maximum yield was reached with the maximum yield is reached with conventional open furrows with all water management techniques except tied furrows which perform best with the minimized water supplied by rain fall (Fig. 3). A similar result was stated by Babikir et al (2017). However, superiority of tied furrows is clear in the second season for all cases of water management techniques. The differences in the second season are significant for all treatments and their interaction. The same trend can be deduced from data of combined effects of the two seasons. This result is in agreement with Asif et al (2015) who reported that growth and yield attributes particularly seed yield of sesame was significantly ($P < 0.05$) affected by all the levels of field planting geometry and amount of irrigation regimes. These results is confirmed by Hailu et al (2018) studied Sesame yield Response to deficit Irrigation and water harvesting techniques (alternate furrow, fixed furrow, and conventional furrow in Ethiopia irrigated agriculture, in two season ,who indicated that the highest mean yield was obtained from both treatment s with highest and lowest water amounts when conventional furrow application methods followed by using alternate (wide furrows). Hailu et al (2018) attributed the superiority of open ridge-furrow rainwater harvesting planting pattern to its drainage capacity of high water amount and its storage ability to lessen the effect of water deficits (rain fed) throughout all crop growth stages, but employing water shortage facility would remain unavoidable during some stages of crop growth in arid and semiarid areas. Therefore, supplemental irrigation would still be needed to achieve a higher production.

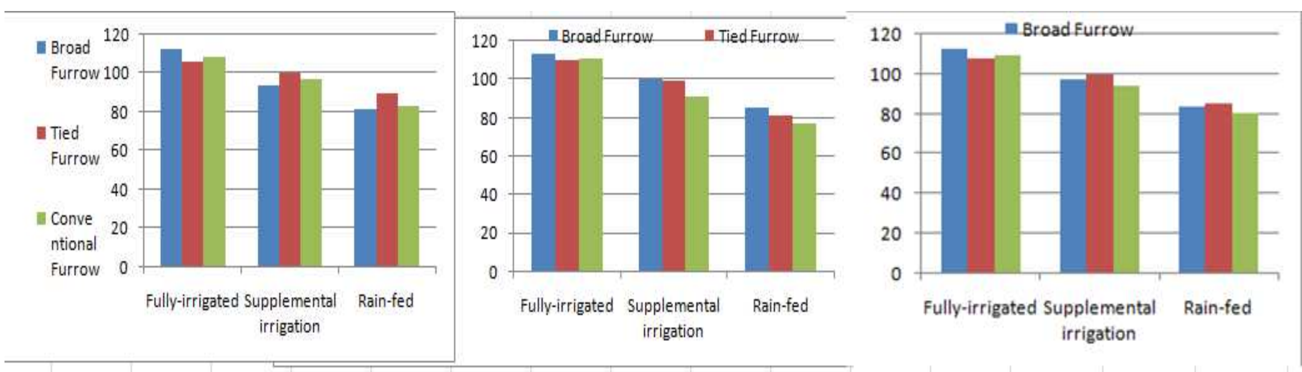

Fig. 2: Variation of water harvesting techniques and water management practices on plant height (cm) for season 2018, 2019 and combines seasons

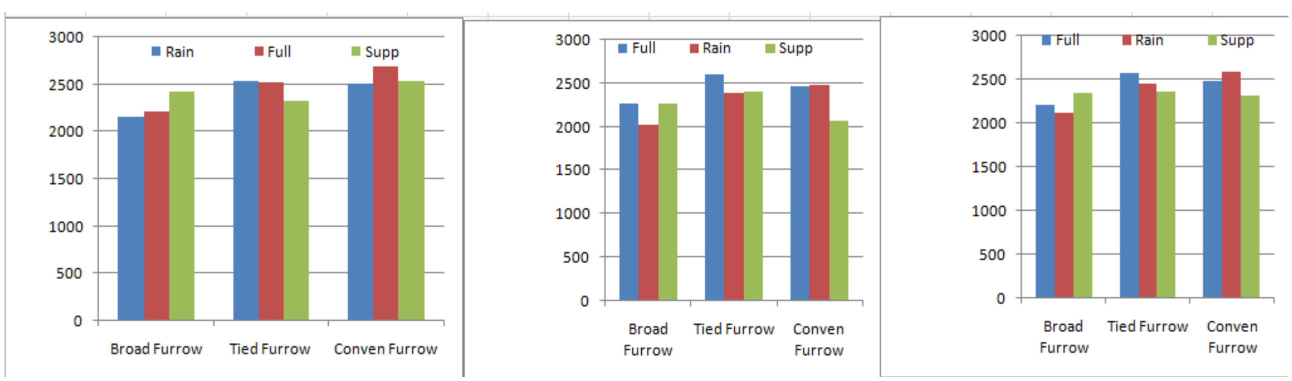

Fig. 3: Variation of water harvesting techniques and water management practices on plant height (cm) for season 2018, 2019 and combines seasons

Conclusions

Ridge-furrow rainwater harvesting planting pattern can lessen the effect of water deficits (rain fed) throughout all crop growth stages, but water shortage would remain unavoidable during some stages of crop growth in arid and semiarid areas. Therefore, supplemental irrigation would still be needed to achieve a higher production. There were statistically significant differences (p=0.01) between moisture regimes and plant height, number of capsules per plant, and seed yield, and the highest seed yield was obtained from fully-irrigated treatment). With application of full irrigation conventional furrows resulted in maximum yield due to drainage of excess and minimization of the adverse effects of water logging. Under the case of low water supply both broad based Furrow and tied furrows store water over the soil surface resulting in improved crop yield. Therefore, the study recommends using the conventional furrow application technique for irrigated agriculture and brad based for rain fed agriculture.

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