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Benchmarking Performance of Sesame Crop (*Sesamum indicum* L.) with Supplemental Irrigation, and Water Harvesting Techniques

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ABSTRACT

A field experiment was conducted in Butana area in season 2019 and season 2020 in a randomized factorial design with three replications to benchmark the performance of sesame crop (Plant height "cm", moisture content "%", number of capsules/ plant, seeds weight (mg), and mean yield "kg/ha") under three water harvesting techniques (tied furrows, semi-circular bund and contour basin " basins enclosed by traditional terraces") assigned to the main plots, and three watering practices (fully-irrigated, supplemental irrigation and rain - fed systems) assigned to sub-plot. Water was applied from a farm reservoir "*Hafir*" to the field by a mobile gun sprinkler. Statistical analysis indicated that both water harvesting techniques and watering application practices significantly ($p<0.05$) improved sesame growth attributes and grain yield. The mean seed yield obtained from supplemental irrigated treatments (467.5 kg/ha) is significantly higher by 29% than yield obtained with rain - fed system (361.3 kg/ha), and equivalent to 72% of that obtained with full irrigation (644.3 kg/ha). When comparing water harvesting techniques semi-circular bund shows significant increase in mean grain yield, and moisture content while tied furrows shows significant increase in seed weight, and plant height. The traditional basin (terraces) resulted in the least values of seed yield and yield attributes except it is only highest for number of seed per capsule. The obtained results showed that, application of supplementary irrigation

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in congestion with semi-circular bund could be an important climate change adaptation strategy in areas with variable rain amount and un even distribution

Keywords**:** Sesame, water harvesting systems, supplementary irrigation, performance benchmarking, rain – fed, *Sesamum indicum*

1. INTRODUCTION

Sesame (*Sesamum indicum* L.) is a tropical and subtropical crop widely grown in Sudan, for its edible oil and other industrial products. It is cultivated in Sudan under rain-fed conditions, in North Kordofan, Gadaref, Damazine, Sinnar, Kassala and Renk [1]. The crop production in these areas fluctuates from one year to another due spatial and temporal variability of rain fall.

Thus, drought coupled with climate change pose a potential problem to sesame production under rain-fed conditions in Sudan which necessitate adoption of some mitigation and adaptation measures. To alleviate the problems associated with drought, and low rain - fed productivity has spurred interest in growing sesame under irrigation [2] or supplemental irrigation [1]in limited areas. Consequently, to achieve the goal of improving sesame production it is necessary to resolve its water constraint by adopting a suitable water harvesting technique. Traditionally people in Butana rain - fed area use in situ water harvesting technique of "truss" cultivation.

Other recommended options are to employ micro catchments techniques of detention basins or tied furrows. A review of early work on sesame reported by [1] emphasizes the importance of supplemental irrigation of sesame in Abu Naama. Other investigations revealed that at least a single irrigation in the season for rain - fed crops was necessary to give a reasonable economic yield [3].

This opens the question of the validity of employing supplemental irrigation of sesame crop in terms of yield to be obtained. For the design of water harvesting system structure to ensure a successful production two alternative rationale were usually used: one is to collect rain fall in receiving area to supplement water deficit in specified cultivated area (micro catchment systems receiving direct rain fall such as semi-circular bund with water storage in the soil). In such method the driving force is to cultivate specified area. The other alternative method is the determination of the area that fully utilizes the available runoff and use the resulting area for storage and cultivation.

The runoff discharge is either fully occupied in a series of detention basins or the discharge is flowing continuously and occupied in an area shaped by open end ridges or the discharge is spreading in a flat area and spill over traces that act as spillways to assure a specified design water application depth.

This calls for running a series of experiments for a more in-depth understanding of response of water harvesting rationale to supplemental irrigation. In addition the suitable system to apply water to the cultivable area (either surface spreading or gun sprinkler) in each rationale need to be determined. Therefore, the objective of this study was to benchmark the performance of sesame crop using plant growth indicators and final grain yield under micro- water harvesting techniques in rain – fed or irrigated areas for purpose of selecting the most suitable techniques to adapt to climate changes.

2. MATERIALS AND METHODS

Study site, location and characteristics

The experiment was conducted in season 2019/2020 and season 2020/2021 at El Gadambalyia village (113001 ha) in Butana rain - fed area (latitudes 13°45′ and 14 ° 15′ N and longitudes 34° 45′ and 35°). This study area is the oldest rain - fed mechanized and subsistence farming schemes in the Butana region of Sudan. The area is semi-arid [4], with annual rainfall ranges between 400 to 500 mm (June to September). The annual mean temperature is (40 °C in summer to 16 °C in winter), with erratic rainfall (350 to 550 mm/annum). The average annual rainfall is less than 44 percent of the potential evapotranspiration. The monthly potential evapotranspiration varies from a minimum of 130 mm in August to a maximum of 205 mm in May with a total average of 1033mm per year [5]. Temperature is high (mean daily maximum temperature is over 40 °C in April and drops to about 17 °C in January). Relative humidity at mid-day varies from 5 to 9 % in March to 57% in August. In the study farm there is a large pit farm reservoir 400 m^3 which last, when full at least to the end of the time of harvesting originally made for domestic uses.

The soil in the study area is cracking Vertisol which is sticky when wet and hard when dry with low infiltration rate (2-3 mm/hr), low nitrogen content (0.212%), low organic matter (1.4%) [6]. As given in Table 1 the ranges of field capacity, wilting point, and bulk density were 31.69–32.38%, 21.20–21.53%, and 1.31–1.37 gm/cm respectively [5].

Table 1. Physical properties of the soil of the study area

Layer thickness (cm)	Field capacity (%)	Wilting point (%)	Bulk density (gm /cm^3)	EC (dS / m)	pH (%)	Lime (%)	Clay (%)	Sand (%)	Silt (%)	Texture
0 - 30	31.94	21.53	1.31	0.200	8.7	20.22	61.64	8.85	29.51	Clay
30 - 60	31.69	21.20	1.32	0.165	7.7	20.03	66.06	8.56	25.35	Clay
60 - 90	32.38	21.53	1.37	0.156	7.5	19.45	66.98	8.76	24.26	Clay

Treatments and Experimental Design

A randomized factorial design with three replications is used. Three watering application systems (fully- irrigated, supplemental irrigation and rain - fed system) are assigned to sub-plot, while three water harvesting techniques (tied furrows, semi-circular bund and continuous contour basin "traditional terraces") are assigned to the main plots. Tied furrows were constructed, by machine using a ridger and ties are made manually, with over flow cross-ties 1.5 m apart, 0.30 m height, and 0.3 m at the base, thus creating mini-basin. The dimensions of the semi-circular bund are height: 0.2 to 0.5 m, base width: 0.70 m, side slopes: 3 : 1, crest width: 0.1 - 0.25 m, and diameter: 12 m - 40 m, while dimensions of contour basin "terraces" are: height : 0.2 - 0.4 m, base width: 0.8 m, side slopes: 1 : 1.5, crest width : = 0.2 m, length of perpendicular basin: 2 - 3 m, spacing of perpendicular basin: 2 - 5 m, and spacing: 20 m, [7]. A spacing distance of 1.5m was kept between plots between, and 1.0 m between sub-plots. The irrigation water is introduced to the watering application systems from constructed reservoir (Hafirs) via a water pump with sprinkler gun carried as one unit with a one wheel hand move cart. For land preparation the field was plowed with disc harrow, leveled, topographically surveyed, divided, and shaped according to specifications of each one of the intended water harvesting technique. Following [5] and [1] Khidir sesame variety was sown manually at spacing of 15 cm apart on 2nd of July 2019 and 2020, and other cultural practices (seed rate, weeding, fertilizer, rain watering) are adopted as recommended by Agricultural Research Corporation (ARC) and they are kept the same for all treatments [2].

Data Collection and Analysis

Each data collected is replicated three times and it includes: 1- crop growth data (days to crop growth stages, yield components "number of branches per plant, number of capsules per plant, number of seeds per capsule and plant height". 2- yield data: "number of seeds per capsule, thousand seed weight, and seed yield in Kg/ha"), 3- Soil moisture data: collected using gravimetric oven dry method (Auger replicated soil samples were taken at soil depth interval of 0.20 m to 0.6 m at two soil depth every two weeks. Collected data was analyzed by descriptive statistics (Statistic 10 software) for determining the mean, standard deviation, coefficient of variation, analysis of variance for determining significant differences at 5%, and mean separation using least significance difference (LSD).

Daily climate data (temperature, humidity, precipitation, wind, sunshine, radiation, soil temperature) were downloaded for thirty years period from Texas A&M's web site at (http://globalweather.tamu.edu).

In reference to [8], [9] and [1] the supplemental irrigation water was applied when 93 mm of soil moisture is depleted. The soil moisture is monitored regularly every seven days and occasionally determined when the soil is observed to start to dry or cracks is seen. Soil moisture is determined by oven dry gravitational method at 0.20 m to one meter depth. In the two seasons, the provision of supplementary irrigation water was made in the period of pod setting. Two supplemental irrigations were given in the first season, while three supplemental irrigations were made during the second season. For full irrigation treatment watering is scheduled and determined by CROPWAT program in reference to crop stage root depth, bulk density, reference evapotranspiration, crop factor (according to Penman-Monteith equation [10], and effective rain fall (measured by automatic rain gauge at the site). Both surface run off and deep drainage were neglected because the area was flat and the heavy clay soils restrict the movement of the water to deeper layers. Hence, the change in soil water storage between two successive samples was taken as the amount of water used by the crop during that period [9].

3. RESULTS AND DISCUSSION

The Overall performance

Table 2 benchmark the performance of sesame crop with the studied watering systems and harvesting techniques. In general, the table shows that there is significant improvement in all growth attributes and seed grain yield by adopting supplemental irrigation over rain - fed watering system. In particular, the mean seed yield obtained from supplemental irrigated treatments (467.5 kg/ha) is significantly higher by 29% than yield obtained with rain - fed system (361.3 kg/ha), and equivalent to 72% of that obtained with full irrigation (644.3 kg/ha). This results is in line with [1] who reported 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 in the clay soil at Abu Naama.- Sudan". When comparing water harvesting techniques semi-circular bund shows significant increase in mean grain yield, and moisture content while tied furrows shows significant increase in seed weight, and plant height.

The traditional basin (terraces) resulted in the least values of yield and yield attributes except it is only highest for number of seeds per capsule. This result is in agreement with [11] who investigated the growth and yield attributes of sesame .He claim that such parameters were significantly ($P < 0.05$) affected by all the levels of field planting geometry and amount of irrigation water regimes.

These results is confirmed by [12] who indicated that sesame yield response to water harvesting techniques of alternate furrow, fixed furrow, and conventional furrow in Ethiopia resulted in the highest mean yield from conventional furrow treatments with both highest and lowest water amounts. [12] attributed the superiority of the ridge-furrow rain water harvesting technique to its overflow capacity to protect the crop from high flood water (water logging) and its capability to store water within the furrows and lessen the effect of water shortage due to longer rain withholding interval.

Importance of supplemental irrigation is emphasized by[13] who indicated that ridge-furrow rain - water harvesting method can lessen the effect of water deficits (rain fed) throughout all crop growth stages, but water shortage would remain unavoidable and detrimental during some stages of crop growth (e.g. flowering stage) in arid and semiarid areas. Therefore, supplemental irrigation would still be needed to achieve a higher production.

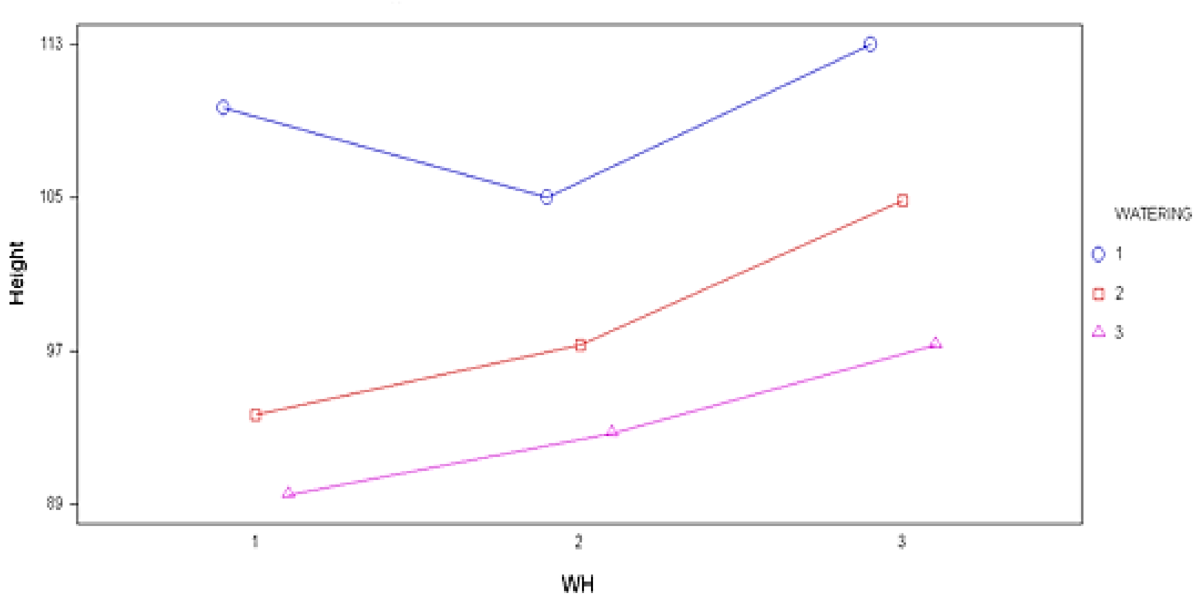
Table 2. Benchmarking performance of sesame crop with watering systems and harvesting techniques

Watering System	**Mean Yield**	**Seed weight**	**Moisture Content**	**Plant Height**	**No Capsule/ plant**
Full Irrigation	644.33 A	3.7272 A	26.600 A	109.22 A	87.967 A
Supplemental Irrigation	467.5 B	3.6494 A	20.711 AB	98.61 B	77.967 B
Rain - fed Irrigation	361.25 C	3.4983 B	16.306 B	93.17 C	60.855 C
SE	6.5252	0.0578	2.144	0.6568	0.4418
Water Harvesting Technique	**Mean Yield**	**Seed weight**	**Moisture Content**	**Plant Height**	**No Capsule/ plant**
Semi-circular bund	377.00 A	3.4906 B	22.700 A	97.61 B	70.228 C
Basin (terraces)	559.28 B	3.6489 A	19.322 B	98.33 B	81.589 A

Tied Furrows	536.81 C	3.7356 A	21.594 AB	105.06 A	74.972 B
SE	3.1919	0.0578	2.1448	0.523	0.5069

Plant Height

Figure 1 shows the variation of plant height (cm) with watering systems and harvesting techniques. The figure indicated that the max height is reached with full irrigation and tied furrows and the least was obtained by the traditional bain "terraces" system with rain - fed irrigation. This result is in agreement with [13] who reported highest yield is obtained in study for with broad based furrows with full irrigation in study for evaluating micro-water harvesting techniques and water management methods for mitigating environmental degradation in rain - fed sesame production in dry lands of Sudan. Improvement in plant height can be ranked for watering systems in descending order of magnitude as: (full irrigation > supplemental irrigation >rain - fed irrigation).

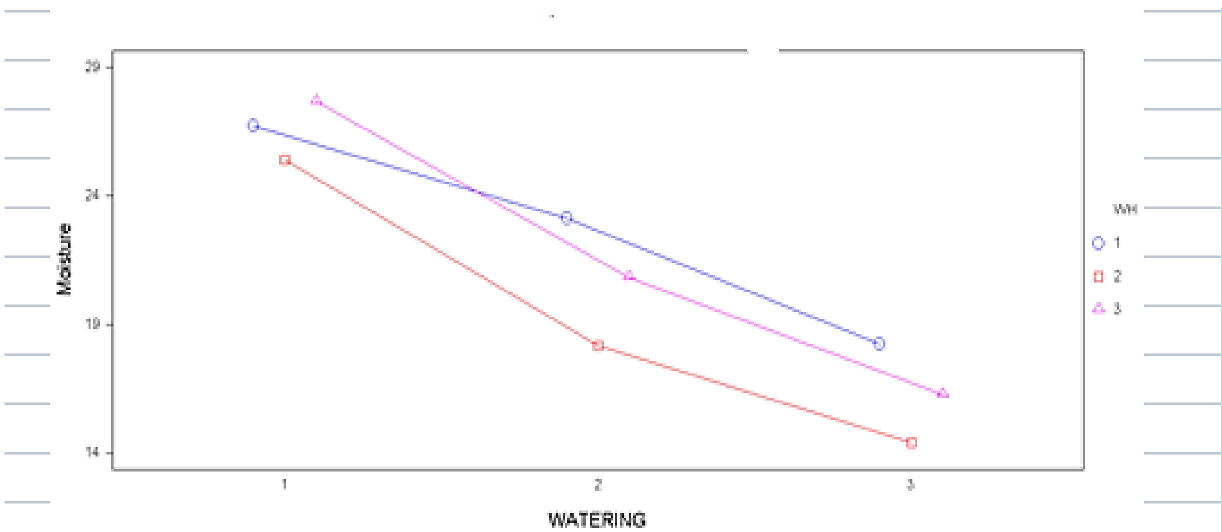


Watering System	1=Full Irrigation	2=Supplemental Irrigation	3=Rain fed Irrigation
Water Harvesting (WH)	1=Semi-circular bund	2= Basin	3=Furrows

Figure 1. Variation of plant height (cm) with the watering systems and harvesting techniques

Moisture Content

The capability of storing soil water (mm) by watering systems and harvesting techniques is depicted in Figure 2. Figure 2 indicated that the treatment of full Irrigation with tied furrows resulted in conserving maximum soil moisture content while minimum moisture content is stored by basins with rain - fed watering. As given in Figure 2 the ability to store soil moisture is due to the characteristics and specification of the type of water harvesting technique and not affected by watering system. This result is supported by [14] who concluded, from a study of the effect of three ways of land surface configuration (flat, ridge and furrow, and bed furrow) on soil moisture and sesame seed yield in Ethiopia that: sesame seed yield is easily affected by soil moisture stress due to reduced rain fall, and good vertisol management options that conserve moisture during dry spell periods and drain excess moisture during wet periods is vital. Accordingly he recommended using the ridge and furrow methods for conserving best soil moisture to obtain the highest seed yield.



Watering System	1=Full Irrigation	2=Supplemental Irrigation	3=Rain fed Irrigation
Water Harvesting (WH)	1=Semi-circular bund	2= Basin	3=Furrows

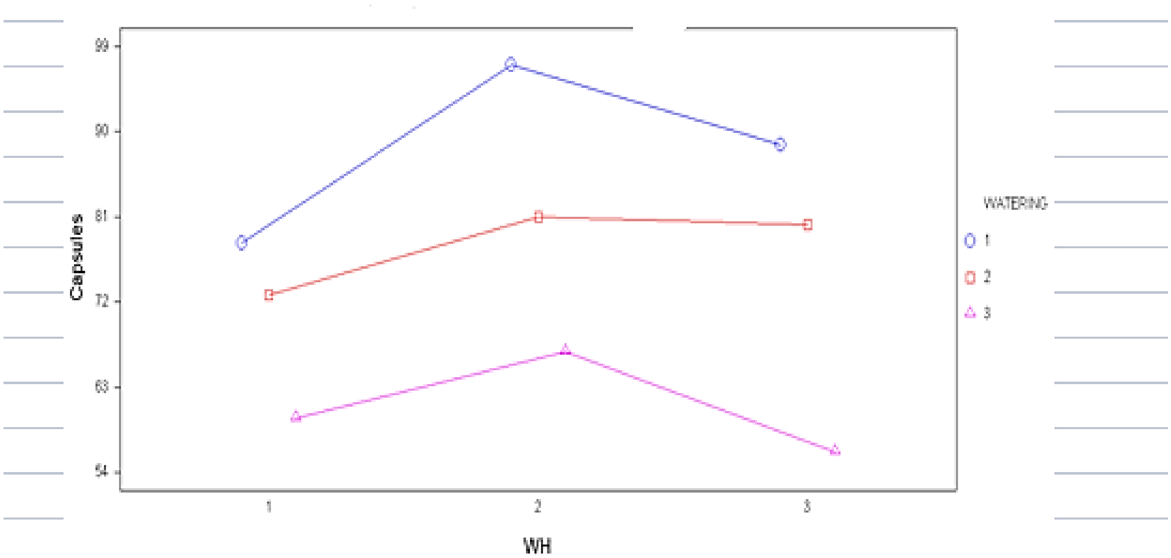
Figure 2. Effect of treatments of water harvesting technique and watering practice on the stored soil moisture (mm)

Number of Capsules/ plant

The Number of Capsules/plant obtained with treatments of water harvesting technique and watering practice is shown in Figure 3. Performance of treatments with respect to mean number of capsules per plant given in Figure 3 reflect that the maximum number is a result of full irrigation compared to other watering systems due to its high soil water storage capability (Figure 2). However, in un expected behavior the basin irrigation resulted in higher values.

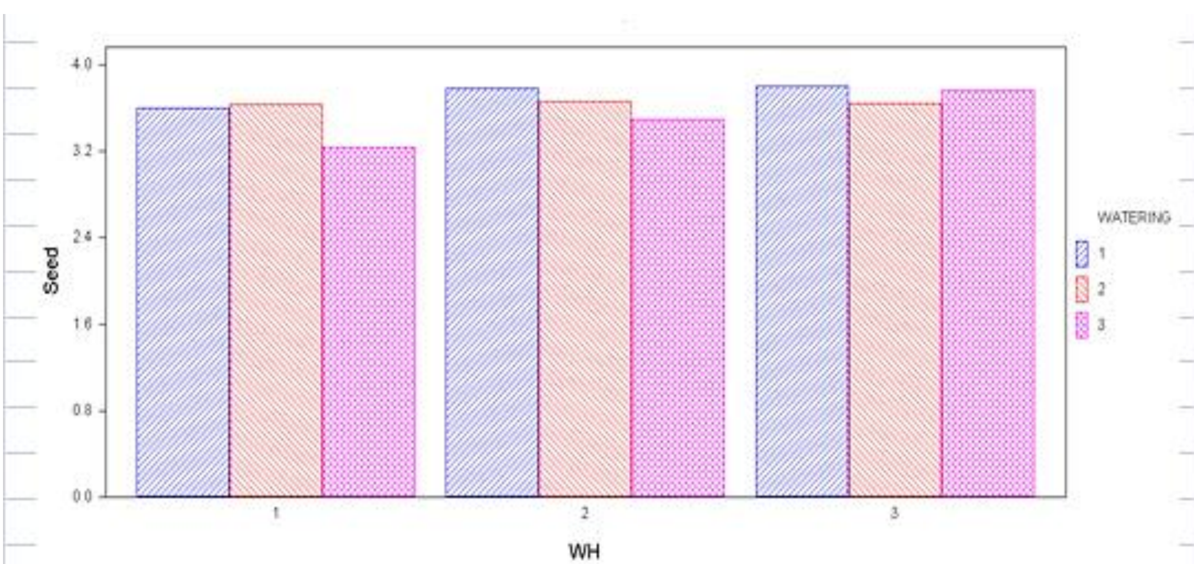
Seed weight

Seed weight (gm) obtained with treatments of the water harvesting techniques and watering practices is depicted in Figure 4. It is evident from the figure that maximum seed weight is obtained by full irrigation with tied furrows while the minimum values resulted from semi-circular bund under rain - fed watering system. As shown in Figure 4 seed weight is a character related to availability of direct water with full irrigation and reflect no significant difference between water stored with tied furrows or basin water harvesting techniques.



Watering System	1=Full Irrigation	2=Supplemental Irrigation	3=Rain fed Irrigation
Water Harvesting (WH)	1=Semi-circular bund	2= Basin	3=Furrows

Figure 3. Number of capsules / plant obtained with treatments of water harvesting technique and watering practice

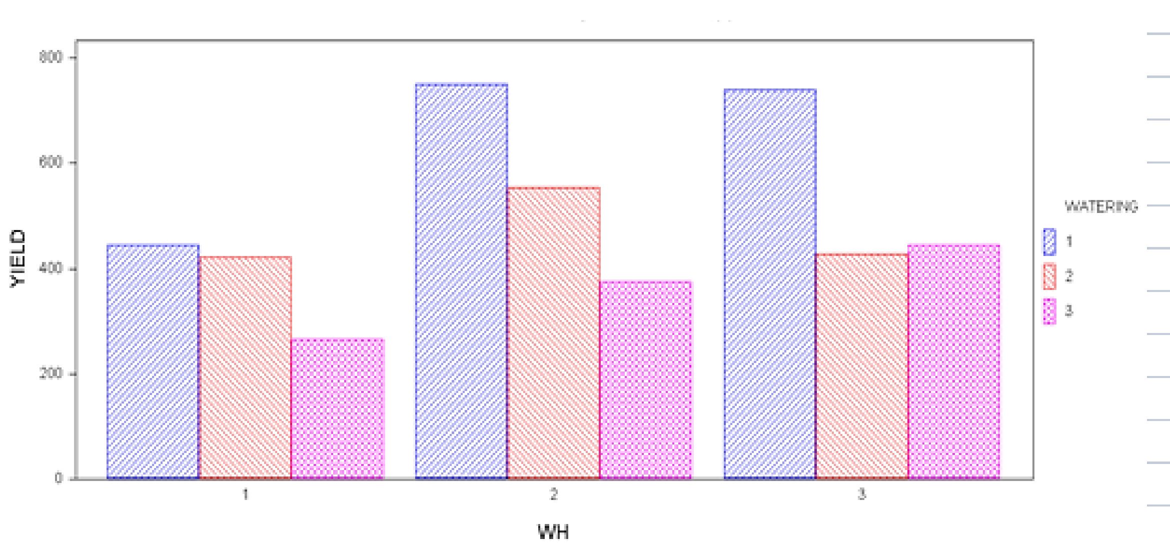


Watering System	1=Full Irrigation	2=Supplemental Irrigation	3=Rain fed Irrigation
Water Harvesting (WH)	1=Semi-circular bund	2= Basin	3=Furrows

Figure 4. Seed weight (gm) obtained with treatments of water harvesting technique and watering practice

Mean Yield

Figure 5 shows seed grain yield (kg/ha) obtained with the treatments of water harvesting technique and watering practice. As expected availability of irrigation water by direct watering (full irrigation) and by water storage with water harvesting method resulted in significantly maximum yield. This can be visualized from the typical yield ranking order with both watering method and harvesting techniques given in: Table 2.



Watering System	1=Full Irrigation	2=Supplemental Irrigation	3=Rain fed Irrigation
Water Harvesting Techr	1=Semi-circular bund	2= Basin	3=Furrows

Figure 5. Seed grain yield (Kg/ha) obtained with treatments of the water harvesting technique and watering practice.

4. CONCLUSIONS

The obtained results showed that, application of supplementary irrigation coupled with semi-circular bund could be an important climate change adaptation strategy in areas with variable rain amount and bad distribution.

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