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Effect of Deficit Irrigation at Different Growth Periods on Yield and Quality of Sugarcane (*Saccharum officinarum l.*) First Ratoon

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aimed to evaluate the effect of deficit irrigation at different growth periods on the yield and quality of sugarcane (*Saccharum spp.*) first ratoon.
Study Design: The study was carried out in Randomized Complete Block Design (RCBD), with three replications.
Place and Duration of Study: A field experiment was conducted during two seasons, 2020-21 and 2021-22 at Guneid Sugarcane Research Center Farm, Sudan.
Methodology: Irrigation deficit treatments were applied when available soil moisture content (ASMC) reached 25% in the root zone at eight different growth periods viz; DT_1: first day to day 50^{th},

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DT_2: day (5th - 100th), DT_3: day (10th -150th), DT_4: day (15th - 200th), DT_5: day (20th - 250th), DT_6: day (25th - 300th), DT_7: day (30th - 350th) and DT_8: day 35th to day 400th after ratoon establishment. These were compared with optimum irrigation (DT_0) which was irrigated at 60% ASMC at the root zone.

Results: The results showed that all deficit irrigation treatments (DT_1 to DT_8) recorded significant cane and sugar yield reduction to the control (DT_0) in the two growing seasons. In this sense, DT_3, DT_4 and DT_5 treatments have recorded the highest cane and sugar yield reduction. Moreover, irrigation deficit affected negatively the sugarcane ratoon yield parameters with low cane water productivity in DT_4 and DT_5 treatments. Therefore, sugarcane first ratoon must be avoided to deficit irrigation at age of 3.3 months to 10.0 months.

Conclusion: According to the results sugarcane first ratoon (Variety Co 6806) established in December under the Central Sudan Agro-climatic zone (Gunied conditions) must be avoided to deficit irrigation at ratoon age of 3.3th month to age 10.0th month (at ratoon age 100 days to 300 days), because of high reduction on cane yield and sugar yield and low in water productivity.

Keywords: Sugarcane; first ratoon; deficit irrigation; growth periods; yield and quality.

1. INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is one of the major cash crops in many countries around the world [1]. It represents about 79% of global sugar production [2]. Sugarcane is grown as an irrigation and strategic crop in the central clay plain of Sudan. Recently in 2021, sugar cane production in Sudan was 5.33 million tonnes. Though Sudan's sugar cane production fluctuated substantially in recent years, it tended to decrease through the 2012-2021 period ending at 5.33 million tonnes in 2021. Ratooning is a practice of growing a full crop of sugarcane from sprouts of underground stubbles left in the field after the harvest of the plant crop. [3] reported that ratooning in sugarcane saves the cost of seedbed preparation, seed material and planting operations and ratoon keeping is 25-30% more economical than plant crop and gets ready for harvest before plant crop with the supplementary advantage of better juice quality and sugar recovery. The scarcity of water mostly affected the growth and yield-related parameters of various crops [4]. Therefore, water deficit conditions show a negative response towards biochemical and physiological processes [5,6]. The effect of water deficit on sugarcane at different stages of its development is not well defined in the literature, affecting estimates of crop behavior when soil moisture is below optimum values [7]. Moreover, all development phases presented deficiency, according to [8,7]. So that the water deficit causes a significant reduction in production in the four development phases of sugarcane [9]. All the physiological and yield-related aspects of a crop were severely affected by drought from the very early stage of seedling to harvesting [10]. Kharif-planted crop suffers due to water stress in their grand growth stage. Germination and tillering are the two important and sensitive phases that are exposed to soil moisture stress, ultimately effects cane and sugar yield [11]. Thus, plants having different growth patterns result in different cane yields [12]. However, the low level of sugarcane productivity that prevailed in some areas of irrigated schemes is attributed to many agronomic factors of which the low level of irrigation water management [13]. The objective of the study was to evaluate the effect of deficit irrigation at different growth periods on the yield and quality of sugarcane **(***Saccharum spp.*) first ratoon.

2. MATERIALS AND METHODS

2.1 Experimental Site

A field experiment was conducted at the Sugarcane Research Center at Guneid farm, Sudan (Latitude 14° 48' and 15° N, Longitude 33° 16' and 33° 22' E and altitude of 386 m above mean sea level), in heavy clay soil, during 2020-21 and 2021-22 growing seasons. The objective was to evaluate the effect of deficit irrigation at different growth periods on the yield, and quality of sugarcane **(***Saccharum spp.*) first ratoon, under the Central Sudan Agro-climatic zone (CSAZ). The test crop was the sugarcane Co 6806 variety, which is occupying around 90% of cultivated areas. CSAZ is classified as semi-arid, with a maximum air temperature range of 31.6- 43.7 °C, minimum air temperature range of 12.8-25.7 °C, Relative humidity ranges between 22% to 83% (Table 1), also annual rainfalls were 191 mm and 236 mm at two growing seasons respectively [14]. The field experiment soil has been described as Remaitab series (subclass S2v) which is Smectitic alluvium, clay Vertisols with moderate chemical fertility (O.C.% 0.4), low infiltration rate, bulk density was 1.5, quite uniform, and alkaline in reaction (pH paste 8.1).

2.2 Experimental Design

The experimental design was a Randomized Complete Block Design (RCBD). The field experimental unit was 112.5 m^2 (15m x 7.5 m) and consisted of five ridges. Sugarcane's first ratoon was established in December and harvested in January at the age of 13 months. The recommended package of cane ratoon practices was followed. Furrow irrigation was used for the experiment and a Parshall flume was installed and a small pump to measure the quantity of water entering the field plot.

2.3 Deficit Irrigation Treatments

The treatments comprised two levels of water supply. The first was optimal irrigation (DT_0) with full Irrigation water applied when the available soil moisture in the root zone reached 60% of the total available soil moisture (40% depletion). The second treatment was applied when available soil moisture content (ASMC) reached 25% in the root zone (75% depletion). These deficit irrigation treatments were; DT_1: at which deficit irrigation was applied at ratoon age one day to day 50, DT_2: at which deficit irrigation was applied at ratoon age 51 day to day 100, DT_3: at which deficit irrigation was applied at ratoon age 101 day to day 150 day, DT_4: at which deficit irrigation was applied at ratoon age day 151 to day 200, DT_5: at which deficit irrigation was applied at ratoon age day 201 to day 250, DT_6: at which deficit irrigation was applied at ratoon age day 251 to day 300, DT_7: at which deficit irrigation was applied at ratoon age day 301 to day 350 and DT_8: at which deficit irrigation was applied at ratoon age day 351 to ratoon age 400 day after ratoon establishment.

2.4 Crop Water Requirement

The reference evapotranspiration (ET_0) for the Guneid area was computed using the FAO-Penman-Monteith approach [15] and CROPWAT software. Seasonal actual evapotranspiration (ET_a) and the irrigation required throughout the growing season were calculated according to the method described by [16]. The seasonal amount of water requirement (CWR) for sugarcane ratoon was determined as a function of the local climate, ratoon age and soil data according to Dooreenbos and Kassam (1979):

$$CWR = ET_0 \times kc \tag{1}$$

where CWR is ratoon water requirement (mm day^{-1}), *ET*o is evapotranspiration of a reference plant under specified conditions, calculated by the class A pan evaporation method (mm day^{-1}), and *K*c is the ratoon water requirement coefficient for sugarcane.

Soil samples were augured from each plot at a depth of 30 cm to determine the soil properties. Then soil moisture content determination by gravimetric method [17] at 20 cm to 60 cm depth using an auger and Tensiometer. Sampling was made one day before irrigation and three days after irrigation throughout the growing seasons.

2.5 Agronomic Parameters

First Sugarcane ratoon yield and quality parameters were recorded at the harvesting date.

2.5.1 Cane yield (TC/ha)

Cane yield and yield components viz; cane yield (tc ha^{-1}), stalk population (000 ha^{-1}), stalk height (cm), stalk diameter (cm), number of nodes per stalk, intermodal length (cm) and stalk weight (kg) were recorded.

2.5.2 Cane quality

Random samples of ten millable stalks were collected from each plot from juice analysis. The juice quality parameters including total soluble solids cane (brix % cane), sucrose per cent (pol % cane), purity %, estimated recoverable sugar per cent (ERS%), and fiber % determined from juice analyzed according to [18] methods of analysis.

2.6 Water Productivity (WP)

Water productivity is one way of irrigation performance indicators. It is defined as the ratio of crop yield to seasonal irrigation water applied including rainfall [19], it was calculated by using the following equation:

$$WP = Y/SI \tag{2}$$

whereas WP is water productivity (kg ha^{-1} m^{-3}), Y is the yield (kg) and SI is the seasonal irrigation water applied including rainfall (m^3).

2.7 Statistical Analysis

Data collected were analyzed using the analysis of variance (ANOVA) technique to evaluate the differences among treatments. Means were separated using the least significant difference (LSD) at the 5% level of significance [20].

3. RESULTS AND DISCUSSION

3.1 Crop Water Requirements (CWR)

Table 1 shows the climatic data of the experimental area for the years 2019 to 2021. Results indicated that the CSAZ climate is semi-arid, the maximum air mean temperature was 38 °C, the minimum air temperature mean was 20 °C, and the relative humidity mean was 53%. Also, annual rainfall was 191 mm and 236 mm in the two growing seasons respectively. Table 2 shows the water requirements of sugarcane as ratoon cane during the irrigation seasons. Results indicated that the highest ratoon water needs were 9.91, 9.32, 7.84 and 8.91 mm/day in March, April, May and June respectively. This is the Grand growth stage in which sugarcane ratoon needs a large amount of water when the lowest ratoon water needs in the initial and tillering stages ranged from 2.9 mm/day to 4.2 mm/day and late season stage with a value of 4.0 mm/day to 4.8 mm/day water requirements, respectively. The effective rainfall (Re) was recorded from July to September. In December before the sugarcane first ratoon has been harvested, crop water requirements were zero, because this month in this study was a dry-off period of the sugarcane first ratoon to improve sugarcane quality. [21] found that sugarcane needs supplemental irrigation of 508.8 mm/season to cane plant and 486.5 mm/season to ratoon cane with a higher frequency of irrigation in the development phase II.

3.2 Effect of Deficit Irrigation on Cane Yield Parameters at Different Growth Periods of Sugarcane First Ratoon

In Table 3 and Table 4, it was clear that deficit irrigation displayed a negative effect on the cane yield of the first ratoon. Cane yield parameters which were arranged and analyzed were; stalk height, stalk diameter, intermodal length and stalk population during the two growing seasons. Analysis of variance showed that deficit irrigation treatments at different growth periods of sugarcane ratoon significantly reduced stalk height, and stalk diameter in sugarcane ratoon due to water stress-restricted photosynthesis, elongation and lateral enlargement. Data which was shown in Table 3 and the finding were in coincided with [22]. Also, stalk height, stalk diameter and intermodal length were reduced when water deficit irrigation was applied at all eight growth periods compared to the optimum irrigation treatment.

Moreover, deficit irrigation during grand growth periods of sugarcane ratoon reduced rates of stalk elongation and internode length (DT_4 and DT_5). Similar results were found when [23] applied water stress, he observed reduction rates of plant elongation and node increment and there is a close relationship between plant height and stem diameter. In this sense, the intermodal length significantly influences the yield of sugarcane. Optimal irrigation practice (DT_0) which gave 10.5 cm intermodal length during the first and second seasons, compared to 8.7 and 8.5 when deficit irrigation treatments DT_4 and DT5 were applied. Insipid of plant density is a major constituent of sugarcane yield, the effect of deficit irrigation application on stalk population during 2020-21 and 2021-22 was not significant (Table 4). Tillering which provides the plants with the optimum number of stalks needed for a good yield is known to be affected by the availability of irrigation water. Water deficit treatments considerably decreased the sugarcane ratoon population compared with optimum irrigation treatment which produced an intensive plant population. The reduction of plant population when water deficit was applied to sugarcane first ratoon was probably due to a reduction in the number of tillers per stool.

Various research studies reported that water influence on sugarcane production due to its effect on yield parameters [24]. In relationship to the improvement of water use efficiency, optimum irrigations are necessary to gain maximum cane length, cane diameter, plant height and ultimately more fresh cane yield [25-27] reported positive correlation amid variables and productivity that increased with irrigation quantity which causes a direct rise in cane yield. [23] who reported that the water deficit reduced the number of tillers per plant. Most growth of the stalk occurs during the grand growth phase, lack of moisture results in lower nutrient uptake as nutrients are taken up in solution. This affects the elongation of internodes negatively resulting in reduced growth of stalk height and circumference, leaves responsible for photosynthesis, the production of sugar storage tissues and ultimately stalk weight which all significantly restrict sugarcane yield [28]. Therefore, stalk height and circumference determine the yield of sugarcane significantly and they are greatly influenced by water [29]. [30] found that irrigation regimes significantly affected cane length and diameter. Under water stress conditions the height and yield of sugarcane are negatively affected hence yield also reduces [28].

Moreover, [30], found that the number of millable canes had a direct correlation with the irrigation regime level. Also [31] reported that deficit irrigation with a low level of water stress at tillering increases sugarcane plant numbers. The number of millable canes obtained with optimum irrigation was significantly the highest compared to the rest of the treatments. The reduced competition of sugarcane for nutrients, moisture and light might have helped in profuse tiller production and low shoot mortality resulting in realizing a higher number of millable canes [32]. [21] reported that water stress restricted photosynthesis, elongation and lateral enlargement. [33] were observed that the furrow method, when irrigation was applied at longer intervals. As the result, the internodes' length and plant height were reduced. [23] found that water stress reduced the number of tillers per plant, reduced rates of plant elongation and node increment and there is a close relationship between plant height and stem diameter. [32] confirmed that due to the increase in competition of plant cane for nutrients, moisture and sunlight. [34 and 35] revealed that continuous availability of nutrients as per crop requirement and favorable soil moisture throughout the growth period of sugarcane increase cane yield.

3.3 Effect of Deficit Irrigation on Yield Quality Parameters at Different Growth Periods of Sugarcane First Ratoon

Yield quality parameters viz; Total soluble solid (Brix % cane), sucrose content in cane (pol % cane), Purity % in juice, Fiber % and estimated sugar recovery percentage (ERS %) were affected by deficit irrigation applied at different growth period of sugarcane first ratoon. Although water deficit influenced negatively sugarcane quality parameters, quality parameters such as brix and pol were not affected by cultural practices; Juice quality mainly depends on the genetic nature of the variety [36].

Insipid of the total soluble solid (brix %) is determining the total sugar production, the deficit irrigation application method failed to affect brix % significantly in sugarcane first ratoon (Table 5). However, deficit irrigation treatments brix % ranged from 15.4 to 15.9% during the first season and from 15.7 to 17.2% during the second season. In the case of $DT_{5,}$ DT_2 and DT_8 deficit irrigation treatments showed a high value of brix % in comparison to the other deficit irrigation treatments. These results are in agreement with those of [37] who reported that the quality of sugarcane did not vary.

Sucrose content in cane (pol %) is controlled by the genetic makeup of a variety and climatic conditions. Data on pol % is influenced by different deficit irrigation treatments are presented in Table 5. Thus, deficit irrigation application treatments did not exhibit any influence on the pol %. In case $DT_{4,}$ DT_5 and DT_8 deficit irrigation treatments showed a high value of sucrose content in comparison to the other deficit irrigation treatments. Moreover, $DT_{8,}$ deficit irrigation treatment which was applied during the maturity stage gave the highest pol per cent in the mean of two growing seasons (11.7%), because weather factors prevailed during the maturity stage and play a major role in the quality parameters of sugarcane. Pol % ranged from 10.50 to 11.50% and from 11.20 to 11.9% in the first and second seasons, respectively. These results are in line with those of [38] who reported that juice quality parameters such as sucrose were not affected by deficit irrigation treatments. In Table 5, the result of the estimated sugar recovery percentage (ERS %) indicated that ERS % was improved consistently during both the years of the study with the same trend of pol %. So deficit irrigation treatments namely **$DT_{4,}$ DT_5** and **DT_8** have a high value of ERS % compared to the other treatments, but the difference was low significant. The early development of millable canes with uniform maturity at harvest under deficit irrigation might have resulted in higher sugar recovery value. The differences between treatments didn't reach the significance level. However, all deficit irrigation practices involved in the present investigation improved the percentage of cane juice recovery. Pure sugar is the ultimate goal of cane crop production and is mainly controlled by the genetic makeup of the variety. Thus, the water deficit factor has little effect on sugar recovery during each season of investigation.

The data about cane juice purity as influenced by different deficit irrigation treatments are presented in Table 6. The results revealed that the purity of cane juice was affected not significantly by deficit irrigation application. Under different deficit irrigation treatments, cane juice purity % ranged from 81.0 to 84.3 and 81.2 to 85.2 during 2020-21 and 2021-22. The results showed that DT_1, DT_2 and DT_4 treatment obtained the highest purity % values of 83.7, 84.0 and 84.4 as a mean of two growing seasons. While DT_3, DT_5 and DT_8 recorded the lowest purity % values of 82.5, 82.8 and 82.8 respectively. So, this means that there was no significant association between cane yield and traits for juice parameters like purity % in sugarcane ratoon. Genetically fiber % is a controlled feature of the sugarcane crop. The fact that fiber per cent was mainly controlled by varietal genetic makeup was proved and thus fiber was not affected significantly during each year of study. Table 6 showed there was no significant difference between different water deficit treatments on fiber % cane in the second season. DT_0, DT_3, and DT_8 treatments recorded the lowest fiber % cane values in a mean of two growing seasons were 17.9%, 17.7%, and 17.7%, while DT_4, DT_5, DT_6, and DT_7 achieved the highest fiber % values of cane 18.7, 18.8, 18.5, and 18.5 respectively. The adoption of full irrigation resulted in an improvement in cane juice quality which was reflected in the reduced cane fiber % in comparison to deficit irrigation treatments.

3.4 Effect of Deficit Irrigation on Cane Yield at Different Growth Periods of First Ratoon

Table 4 showed that the effects of deficit irrigation on one cane stalk weight and total cane yield, the result was shown that the weight of one cane and cane yield is positively correlated which was agreed with [39]. Moreover, there were significant differences in deficit irrigation treatments on cane yield (Table 4). So, the optimum irrigation treatment (DT_0) recorded the highest mean cane yield was 88.7 tc ha^{-1}, compared to DT_4, and DT_5 treatments which recorded the lowest mean values of cane yield of 74.4 tc ha^{-1} and 74.5 tc ha^{-1}, for the reason that high biomass crop requires large quantities of water for maximum production [40]. Deficit irrigation treatment reduced the cane yield of sugarcane ratoon which is clearly shown in Fig. 1. Moreover [41] reported that water stress reduced cane yield and dry weight of sugarcane. On the other hand, deficit irrigation treatments recorded high values of cane yield in the second season compared to the first one, the reduction of ratoon cane yield in the first growing season was probably due to a reduction in total rainfall and other climatic factors change.

3.5 Effect of Deficit Irrigation on Sugar Yield at Different Growth Periods of the First Ratoon

Perusal of data on sugar yield as influenced by deficit irrigation treatments revealed significant differences between the treatments (Table 6) and (Fig. 2). Sugar formation is dependent on climatic parameters and associated with an adequate water supply. The sugar yield is a function of cane yield and hence trend was similar as in cane yield. The sugar yields in various treatments followed the same trend as that of cane yield. Markedly the highest sugar yield was recorded in DT_0, DT_1, DT_2 and DT_8 which gave significantly higher sugar yields of 7.2 ts ha^{-1}, 6.6 ts ha^{-1}, 6.3 ts ha^{-1} and 6.8 ts ha^{-1} respectively. The mean of both two growing seasons, this attributed to the fact that deficit irrigation with a low level of water stress at tillering (DT_1, and DT_2, treatments) increase sugarcane plant numbers [31] and deficit irrigation at late season (DT_8) improve sugar cane quality and the crop is well ripened before harvest [42]. Furthermore DT_0, DT_5 and DT_8 were recorded high in Brix %, pol % cane and ERS % cane. However, deficit irrigation treatment DT_4 has significantly ($P \leq 0.05$) increased purity per cent in juice when compared to other treatments, while water deficit during the mid-season stage DT_4, and DT_5 were applied after fall significantly decreased ($P \leq 0.05$) cane and sugar yield compared to other treatments. This could mainly be due to the fact that the mid-season stage is most sensitive to water stress [39]. But deficit irrigation before dries off period after the rainy season has significantly ($P \leq 0.05$) decreased cane and sugar yield (DT_6 and DT_7), climatic data in Table 2 showed that last October and November applied to have high relative humidity % and high in evaporation (mm) that lead to a high reduction in sugar yield.

3.6 Effect of Water Deficit on the Number of Irrigations Applied and Water Saved of First Ratoon

The effect of water deficit on the number of irrigations applied and water saved at different growth Periods of sugarcane first ratoon under CSAZ as shown in Table 7. Results have shown that a huge amount of water has been saved when deficit irrigation treatments DT_2, DT_3 and DT_5 were applied at the growth periods of ratoon and the water saved were 6100M^3 ha^{-1}, 5500M^3 ha^{-1}, and 5200M^3 ha^{-1} respectively. All deficit irrigation treatments saved water through the growing season which ranged from 6100 M^3 ha^{-1} to 3800 M^3 ha^{-1}. Several irrigations were applied in the sugarcane first ratoon which was established in December and harvested in January under Gunied conditions, Sudan was thirty in optimum irrigation treatment and was twenty-seven when deficit irrigation treatments were applied. Deficit irrigation is not only effective in irrigation but also in the amount of water which was used during the irrigation season.

3.7 Effect of Water Deficit at Different Growth Periods on Water Productivity of Sugarcane First Ratoon

Table 8 shows the effect of deficit irrigation on cane water productivity of sugarcane first ratoon. High values of water productivity were recorded when deficit irrigation treatments DT_1, DT_2, DT_3, and DT_6 were applied followed by DT_7, DT_8, DT_0, DT_4, and DT5 respectively. Moreover, cane yield reduction was not significant when compared to the benefits of the saved water. These results were agreed with [43], who reported that deficit irrigation saved significant irrigation water without significant yield losses.

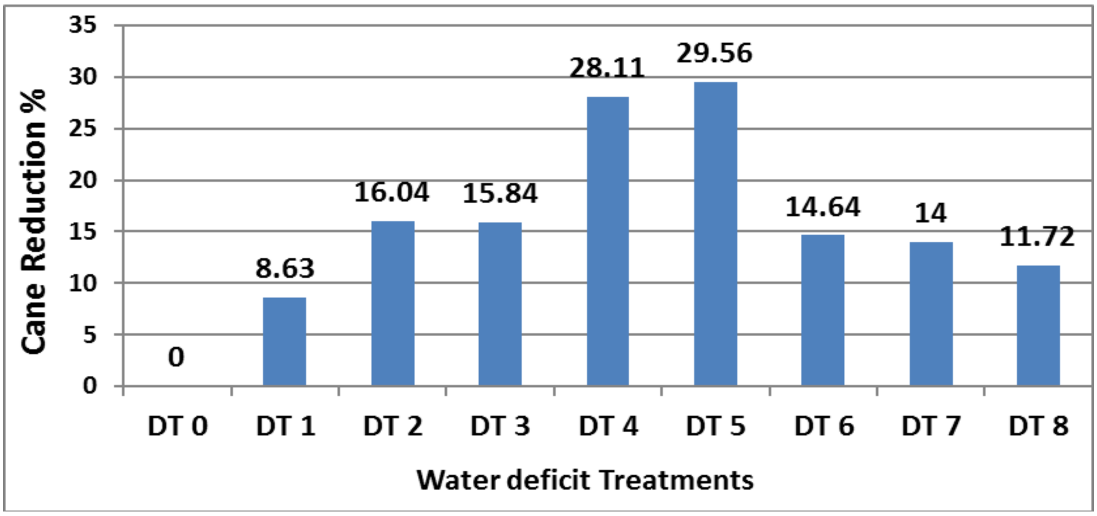

Fig. 1. Effect of deficit irrigation on cane yield reduction % of first ratoon, seasons 2020-21 and 2021-22

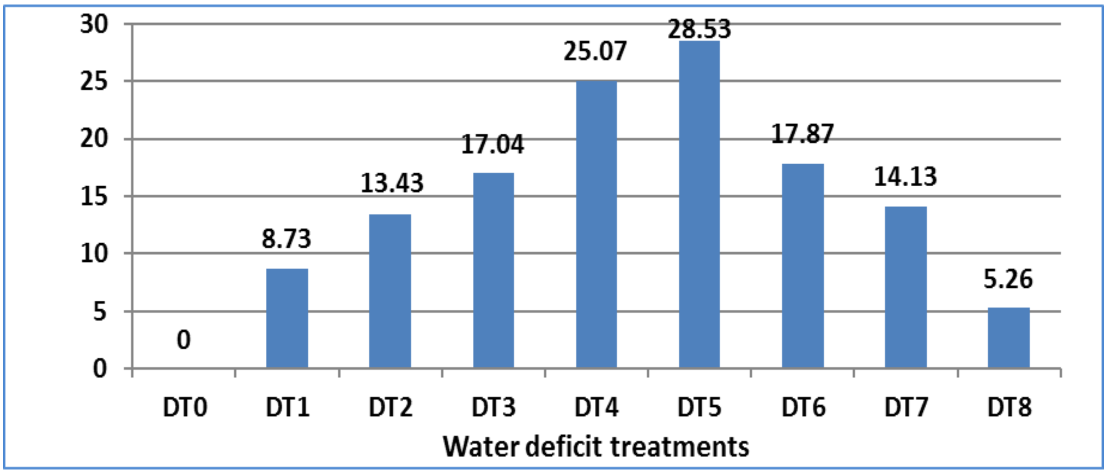

Fig. 2. Effect of deficit irrigation on sugar yield reduction % of first ratoon, seasons 2020-21 and 2021-22

Table 1. Climatic data of the experimental area for the study years (2019-2021)

Years	Climatic data	Months											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2019	Max. Temperature (^oC)	36.1	36.1	37.5	41.7	43.1	38.46	37.4	32.7	34.9	35.0	37.2	33.9
	Min. Temperature (^oC)	17.2	19.1	18.8	22.5	25.7	24.4	23.5	22.8	23.0	22.1	18.8	15.1
	R. humidity (%)	41.7	32.2	23.1	19.7	30.7	60.2	68.6	80.6	76.6	70.2	42.6	41.6
	Wind speed ($m\ s^{-1}$)	1.9	2.1	1.9	1.7	2.4	4.0	4.0	2.5	2.8	1.0	1.1	1.5
	Evaporation (mm)	14.4	16.8	18.1	22.8	22.0	20.9	16.9	6.7	6.4	6.4	12.0	12.1
	Rainfall (mm)	-	-	-	-	-	15.6	43.4	129.7	69.7	8.4	-	-
2020	Max. Temperature (^oC)	31.6	33.5	37.9	41.4	42.6	41.5	37.1	33.2	34.3	38.5	36.6	35.6
	Min. Temperature (^oC)	12.8	14.4	24.8	22.0	25.6	24.9	22.2	20.1	22.7	24.7	18.3	16.4
	R. humidity (%)	37.2	32.7	24.1	22.0	31.3	47.4	67.4	83.1	76.9	62.3	41.3	44.1
	Wind speed ($m\ s^{-1}$)	1.8	2.0	1.9	1.7	1.8	3.7	4.5	2.6	3.8	1.4	1.4	1.4
	Evaporation (mm)	13.2	14.7	23.9	18.9	17.9	18.2	18.2	6.3	7.2	11.2	14.4	12.8
	Rainfall (mm)	-	-	-	-	-	-	33.5	142.1	15.4	-	-	-
2021	Max. Temperature (^oC)	33.3	34.1	40.2	39.2	40.0	40.5	35.9	34.9	35.5	39.0	38.2	32.5
	Min. Temperature (^oC)	15.6	16.3	22.6	21.8	24.3	25.6	22.0	20.1	22.2	22.7	22.5	14.5
	R. humidity (%)	45.8	39.0	33.3	27.5	41.8	51.3	73.5	72.9	78.3	53.4	26.0	33.0
	Wind speed ($m\ s^{-1}$)	6.82	1.90	2.27	1.97	2.21	2.77	4.3	2.4	2.3	0.8	0.9	1.5
	Evaporation (mm)	13.3	15.5	19.0	21.3	16.2	17.7	11.6	9.4	7.0	10.5	17.5	16.5
	Rainfall (mm)	-	-	-	-	10.3	40.0	58.7	79.6	47.4	-	-	-

Table 2. Sugarcane first ratoon water requirements of the experimental area for two growing seasons (2020/21-2021/22)

Month		ET_0 (mm/day)			k_c	CWR (mm/day)			Rainfall (mm/day)		
1st Season	2nd Season	1st Season	2nd Season	Mean		1st Season	2nd Season	Mean	1st Season	2nd Season	Mean
Dec 2019	Dec 2020	4.81	4.94	4.88	0.6	2.90	2.96	2.93	-	-	-
Jan 2020	Jan 2021	5.32	5.02	5.17	0.8	4.26	4.02	4.14	-	-	-
Feb	Feb	6.10	5.96	6.03	1.1	6.71	6.56	6.64	-	-	-
Mar	Mar	7.31	7.93	7.62	1.3	9.50	10.31	9.91	-	-	-
April	April	7.73	7.80	7.77	1.2	9.28	9.36	9.32	-	-	-
May	May	7.93	7.74	7.84	1.0	7.93	7.74	7.84	-	10.3	5.0
June	June	9.74	8.08	8.91	1.0	9.74	8.08	8.91	-	40.0	20.0
July	July	7.25	6.30	6.78	1.0	7.25	6.30	6.78	33.5	58.7	46.0
Aug	Aug	4.90	5.74	5.32	1.0	4.90	5.74	5.32	142.0	79.6	111.0
Sept	Sept	5.70	5.36	5.53	1.0	5.70	5.36	5.53	15.5	47.4	32.0
Oct	Oct	6.00	5.30	5.65	0.9	5.40	4.77	5.09	-	-	
Nov	Nov	5.40	5.02	5.21	0.8	4.00	4.02	4.01	-	-	
Dec 2020	Dec 2021	Dry Off	Dry off	-	-	-	-	-	-	-	
Annual	-	-	-	-	-	-	-	-	191.0	236	214.0

CWR is crop water requirement (mm day^{-1}), ETo is evapotranspiration (mm day^{-1}), and Kc is crop water requirement coefficient for sugarcane

Table 3. Effect of deficit irrigation on stalk height, stalk diameter and internodal length at different growth periods of sugarcane first ratoon

Treat.	Stalk height (cm)			Stalk diameter (cm)			Internodal length (cm)		
	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean
DT_0	216.0 a	227.5 a	222.0	2.25 a	1.92 a	2.1	10.5 a	10.5 a	10.5
DT_1	197.3 b	205.9 ab	202.0	2.25 a	1.88 ab	2.1	10.1 a	9.5 bc	9.8
DT_2	186.7 d	189.3bcd	188.0	2.16 ab	1.83 abc	2.0	9.0 ab	9.4 bc	9.2
DT_3	189.0 cd	202.2 abc	196.0	2.22 ab	1.84 abc	2.0	9.8 ab	8.8 cde	9.3
DT_4	164.7 f	176.7cd	171.0	2.10 ab	1.78 c	1.9	8.9 b	8.5 de	8.7
DT_5	160.0 g	163.0 d	162.0	2.06 b	1.76 c	1.9	9.2 ab	7.8 e	8.5
DT_6	177.3 e	186.2 bcd	182.0	2.16 ab	1.82bc	2.0	9.4 ab	8.5 de	9.0
DT_7	189.3cd	188.2 bcd	189.0	2.23 a	1.83ab	2.0	10.0 a	9.3 bcd	9.7
DT_8	194.0 bc	198.2 bc	196.0	2.24 a	1.84abc	2.0	10.1 a	10.4 a	10.3
Mean	183.7	193.0	188.0	2.18	1.83	2.0	9.7	9.2	9.5
CV%	1.77	8.7	-	4.40	3.07	-	8.99	6.1	-
LSD ($p \leq 0.05$)	5.64	29.1	-	0.17	0.097	-	1.51	0.96	-

Means sharing the same letters do not differ significantly at the 5% level of significance.

***DT_0**: Optimum irrigation, which was irrigated at 60% available soil moisture content at the root zone. **DT_1 to DT_8**: Deficit irrigation was applied at the first growth period to deficit irrigation at the eighth growth period (from day one to day fifty after ratoon establishment and from day 350 to day 400 at the eighth period). All these treatments were irrigated at 25% available soil moisture content at the root zone*

Table 4. Effect of deficit irrigation on stalk population, stalk weight and cane yield at different growth periods of sugarcane first ratoon

Treat.	Stalk population (000 ha^{-1})			Stalk Weight (kg)			Cane yield (Ton ha^{-1})		
	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean
DT_0	131.0 a	135.0 a	133.0	0.94 a	0.80 a	0.9	83.3 a	94.0 a	88.7
DT	131.0 a	132.0 a	132.0	0.81 b	0.71ab	0.8	76.1 b	85.9 a	81.0
DT_2	128.0 a	128.0 a	128.0	0.66 e	0.69 abc	0.7	71.7 d	77.0 ab	74.4
DT_3	130.0 a	129.0 a	130.0	0.72 cd	0.65 bc	0.7	72.0 d	77.0 ab	74.5
DT_4	126.0 ab	124.0 a	125.0	0.64 e	0.60 c	0.6	60.1 e	67.4 b	63.8
DT_5	114.0 b	118.0 a	116.0	0.56 f	0.59 c	0.6	59.0 f	65.9 b	62.5
DT_6	127.0 a	128.0 a	128.0	0.68de	0.62bc	0.7	74.0 c	77.0 ab	75.5
DT_7	129.0 a	129.0 a	129.0	0.73 c	0.65 bc	0.7	74.3 c	77.7 ab	76.0
DT_8	129.0 a	131.0 a	130.0	0.77 bc	0.67 bc	0.7	73.6 c	82.9 ab	78.3
Mean	127.0	128.0	128.0	0.72	0.67	0.7	71.6	78.3	75.0
CV%	6.03	9.2	-	4.02	9.33	-	0.77	12.75	-
LSD ($p \leq 0.05$)	13.3	20.3	-	0.94 a	0.80 a	-	0.96	17.28	-

Means sharing the same letters do not differ significantly at the 5% level of significance

***DT_0**: Optimum irrigation, which was irrigated at 60% available soil moisture content at the root zone. **DT_1 to DT_8**: Deficit irrigation was applied at the first growth period to deficit irrigation at the eighth growth period (from day one to day fifty after ratoon establishment and from day 350 to day 400 at the eighth period). All these treatments were irrigated at 25% available soil moisture content at the root zone*

Table 5. Effect of deficit irrigation on cane Brix %, cane Pol % and ERS % at different growth periods of sugarcane first ratoon

Treat.	Brix % cane			Pol % cane			ERS %		
	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean
DT_0	15.9 [a]	16.5 [abc]	16.2	11.0 [a]	11.5 [ab]	11.3	8.0 [a]	8.5 [ab]	8.3
DT_1	15.1 [b]	16.5 [abc]	15.8	10.5 [a]	11.7 [ab]	11.1	7.5 [a]	8.7 [ab]	8.1
DT_2	15.4 [ab]	17.0 [ab]	16.2	11.0 [a]	11.8 [ab]	11.4	8.0 [a]	8.8 [ab]	8.4
DT_3	15.5 [ab]	16.7 [abc]	16.1	10.8 [a]	11.3 [b]	11.1	7.9 [a]	8.3 [b]	8.1
DT_4	15.4 [ab]	16.7 [abc]	16.1	11.0 [a]	11.9 [a]	11.5	7.8 [a]	8.9 [a]	8.4
DT_5	15.5 [ab]	17.2 [a]	16.4	10.9 [a]	11.6 [ab]	11.3	8.0 [a]	8.6 [ab]	8.3
DT_6	15.4 [ab]	15.7 [d]	15.6	10.5 [a]	11.2 [b]	10.9	7.5 [a]	8.2 [b]	7.9
DT_7	15.4 [ab]	16.2 [cd]	15.8	10.6 [a]	11.7 [ab]	11.2	7.6 [a]	8.7 [ab]	8.2
DT_8	15.5 [ab]	16.3 [bcd]	15.9	11.5 [a]	11.9 [a]	11.7	7.5 [a]	8.9 [a]	8.2
Mean	15.5	16.5	16.0	10.8	11.61	11.2	7.8	8.61	8.2
CV%	2.36	2.63	-	5.03	3.25	-	7.02	4.38	-
LSD ($p \leq 0.05$)	0.63	0.75	-	0.937	0.65	-	0.94	0.65	-

Means sharing the same letters do not differ significantly at the 5% level of significance

DT_0*: Optimum irrigation, which was irrigated at 60% available soil moisture content at the root zone.* ***DT_1 to DT_8****: Deficit irrigation was applied at the first growth period to deficit irrigation at the eighth growth period (from day one to day fifty after ratoon establishment and from day 350 to day 400 at the eighth period). All these treatments were irrigated at 25% available soil moisture content at the root zone*

Brix*: total soluble solid,* ***Pol****: sucrose content in cane and* ***ERS****: estimated sugar recovery*

Table 6. Effect of water deficit at different growth periods on Purity % in Juice, Fiber % in cane and Sugar yield

Treat.	Purity % in Juice			Fiber % in cane			Sugar yield (Ton ha^{-1})		
	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean
DT_0	83.0 a	85.19 a	84.1	17.9 abc	17.83 a	17.9	6.66 a	7.78 a	7.2
DT_1	82.5 a	84.90 a	83.7	18.0 abc	17.93 a	18.0	5.71 b	7.46 ab	6.6
DT_2	85.5 a	82.56 a	84.0	18.2 abc	18.30 a	18.3	5.74 b	6.76 abc	6.3
DT_3	84.3 a	80.72 a	82.5	17.3 c	18.07 a	17.7	5.62 b	6.36 bc	6.0
DT_4	83.9 a	84.94 a	84.4	19.1 a	18.27 a	18.7	4.81 c	6.01 bc	5.4
DT_5	84.3 a	81.23 a	82.8	18.8 ab	18.83 a	18.8	4.66 c	5.65 c	5.2
DT_6	81.0 a	85.84 a	83.4	18.5 a	18.43 a	18.5	5.55 b	6.31 bc	5.9
DT_7	82.9 a	84.79 a	83.8	18.2 abc	18.73 a	18.5	5.65 b	6.75 abc	6.2
DT_8	81.0 a	84.54 a	82.8	17.8 bc	17.50 a	17.7	6.26 a	7.41 ab	6.8
Mean	83.2	83.86	83.5	18.21	18.10	18.2	5.63	6.72	6.2
CV%	3.5	4.47	-	4.04	4.44	-	7.35	12.93	-
LSD ($p \leq 0.05$)	5.03	6.49	-	1.2740	1.39	-	0.71	1.63	-

Means sharing the same letters do not differ significantly at the 5% level of significance.

DT_0: *Optimum irrigation, which was irrigated at 60% available soil moisture content at the root zone.* ***DT_1 to DT_8***: *Deficit irrigation was applied at the first growth period to deficit irrigation at the eighth growth period (from day one to day fifty after ratoon establishment and from day 350 to day 400 at the eighth period). All these treatments were irrigated at 25% available soil moisture content at the root zone.*

Table 7. Effect of deficit irrigation on water saved at different growth periods of Sugarcane ratoon

Treatments	No. of irrigations applied	No. of Irrigations saved	CWR M^3(000) ha^{-1}/season	Water saved M^3 (000) ha^{-1} /season
$DT_{0\ (control)}$	30	0	20.9	0
DT_1	27	3	17.1	3.8
DT_2	27	3	14.8	6.1
DT_3	27	3	15.4	5.5
DT_4	27	3	16.2	4.7
DT_5	27	3	15.7	5.2
DT_6	27	3	16.2	4.7
DT_7	27	3	16.9	4.0
DT_8	27	3	17.5	3.4

Table 8. Effect of deficit irrigation on water productivity at different growth periods of Sugarcane ratoon

Treatments	CWR M^3 (000) ha^{-1}			Total sugarcane Kg (000) ha^{-1}			Water productivity (WP) Kg (000) $ha^{-1}m^{-3}$		
	1st season	2nd season	Mean	1st season	2nd season	Mean	1st season	2nd season	Mean
$DT_{0\ (control)}$	21.5	20.3	20.9	83.3 [a]	94.0 [a]	88.65	3.90	4.60	4.25
DT_1	17.2	17.0	17.1	76.1[b]	85.9 [a]	81.00	4.43	5.05	4.74
DT_2	14.7	14.8	14.8	71.7 [d]	77.0 [ab]	74.35	4.89	5.19	5.05
DT_3	15.2	15.5	15.3	72.0 [d]	77.0 [ab]	74.5	4.76	4.97	4.87
DT_4	15.9	16.5	16.2	60.1[e]	67.4 [b]	63.75	3.78	4.09	3.94
DT_5	15.3	16.2	15.7	59.0 [f]	65.9 [b]	62.45	3.87	4.07	3.97
DT_6	15.9	16.5	16.2	74.0 [c]	77.0 [ab]	75.5	4.66	4.67	4.67
DT_7	16.5	17.3	16.9	74.3 [c]	77.7 [ab]	76.0	4.5	4.5	4.50
DT_8	16.9	18.2	17.5	73.6 [c]	82.9 [a]	78.25	4.35	4.57	4.46
Mean	16.3	16.9	16.6	71.56	78.3	74.93	4.39	4.64	4.52
C.V %				0.77	12.8	6.79	-	-	-
LSD ($P \leq 0.05$)				0.96	17.28	9.12	-	-	-

Means sharing the same letters does not differ significantly at the 5 % level of significance
CWR: Crop water requirement

4. CONCLUSION

Deficit irrigation treatments (DT_1 to DT_8) recorded a significant effect on cane and sugar yield reduction than the control (DT_0) in the two seasons (2020-21 and 2021-22) under Gunied conditions, Central Sudan Agro-climatic zone. DT2, T3, DT4 and DT5 treatments recorded significantly the highest cane yield reduction was; 16.04%, 15.84%, 28.11% and 29.56%. While DT_3, DT_4, DT_5 and DT_5 treatments recorded significant the highest sugar yield reduction was; 17.04%, 25.07%, 28.53% and 17.87% respectively compared to DT_0 with full Irrigation. High Sugarcane water productivity was recorded at deficit irrigation treatments DT_1, DT_2, DT_3 and DT_6 respectively compared to optimum irrigation (DT_0) as the first ratoon.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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