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Research Article

Effect of Water Deficit at Different Growth Periods on Yield, Quality and Water Productivity of Sugarcane (*Saccharum officinarum* L.) under Central Sudan Agro-climatic Zone

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Abstract: A field experiment was conducted during two consecutive seasons of 2020/21 and 2021/22 at the Sugarcane Research Center Farm – Gunied, (Central Sudan Agro-climatic zone), to evaluate the effect of water deficit irrigation at different growth periods on yield, quality and water productivity of sugarcane (*Saccharum officinarum L.*) Variety Co 6806. The study was designed in Randomized Complete Block Design (RCBD) and replicated three times. Irrigation deficit treatments were applied when available soil moisture content (ASMC) reached 25% in the root zone at eight different growth periods. The eight growth periods were begun from plant age 51th day to day100th at which the first deficit irrigation treatment was applied (DT1), age from day101th to day 150th the second deficit irrigation treatment was applied (DT2), age from day 151th to day 200th the third deficit irrigation treatment was applied (DT3), then at the same growth period length of 50 days fallow the other treatments till DT8 the eight irrigation deficit treatment was applied at crop age from day 401th to day 450th. These were compared with optimum irrigation (DT0) which was irrigated at 60% ASMC at the root zone. Results showed that all deficit irrigation treatments (DT1 to DT8) recorded significant cane and sugar yield reduction than the control (DT0) in the two growing seasons. In this sense, DT1, DT2, DT3, and DT8 treatments have recorded the highest cane and water productivity. Therefore, for sugarcane crop planting in November deficit irrigation must be avoided at the crop age of 6.7th month to age 13.3th month.

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1. Introduction

Sugarcane (*Saccharum spp*.) is a perennial crop, belongs to the family Poaceae, and is economically important for producing sugar and other products, such as electricity and bioethanol. For a long time, sugar is one of the essential components of the human diet (Ramiro et al., 2019). Its importance is realized due to its contribution towards meeting the individual energy requirement. The crop is cultivated in the tropical and subtropical region in an area of about 24.5 million hectares with a production of 1850 million cane tones' and 75.5 tc ha^{-1}. Recently the global harvest exceeded to175 million tons of sugar a year (FAO, 2016). Brazil was the largest producer of sugarcane in the world, followed by India, China, Thailand, Pakistan, and Mexico. While Brazil was still the largest sugar producing country in the 2020/2021 crop year, with 182 million metric tons of sugar as the total global production (FAO, 2021). Sugarcane is one of the most water-demanding crops after rice. For example, depending on the zone, it may take more than 1000 millimetres, i.e. 10 000 cubic metres of water, for a yield of 100 tons per hectare. Depending upon the agro climatic conditions and sugarcane yield water requirement varies (Choudhary et al., 2013). The average water requirement of sugarcane is to the tune of 1200 to 3000 mm. The number of irrigations in sugarcane depends upon the climatic conditions, type of soil, method of planting, and use of manures and fertilizers (Choudhary et al., 2013, Abu Alama et al. 2022). All the physiological and yield-related aspects of a crop were severely affected by drought from the very early stage of seedling to harvesting (Tawfik and El-Mouhamady, 2019). The proper irrigation interval can play a major role in increasing water use efficiency and productivity (Ethan et al., 2016). In India the highest yield was obtained when the crop was irrigated at eight-day intervals during early growth and at sixteen-day intervals during tillering and then every twelve days to maturity (Yahaya et al., 2010). On the other hand, Salgado et al. (2021) showed that suspending irrigation between 45 and 60 days before harvest increases the quality of the juices as well as the yields of the grinding stalks.

Sugarcane is grown as an irrigation and strategic crop in the central clay plain of Sudan; however, the sugar industry in Sudan faced several problems that lead to decreased sugarcane productivity from 93.57 tc ha^{-1} to 75.92 tc ha^{-1} to 49.74 tc ha^{-1} at crushing seasons 2010/2011, 2014/2015 and 2020/2021 respectively in Sudanese Sugar Company. That decrease in sugarcane productivity is due to high production and harvesting costs, lack of water poorly controlled, and the spread of weeds in both the ratoon and main crop (SSC, 2021). Water management plays an important role in enhancing sugarcane productivity stagnating in Sudan and demand for this crop is increasing. The scope for extending sugarcane areas in the country is limited. Under these circumstances, emphasis must be on water management issues that need to be addressed for increasing sugarcane productivity. Therefore, the present study was carried out to assess the effect of water deficit application at different growth periods on sugarcane yield, quality, and cane water productivity under the central Sudan Agro-climatic zone.

2. Material and Methods

2.1. Experimental site

A field experiment was conducted at the Sugarcane Research Center at Guneid farm, (14° 47″ N, 33° 19″ E, and an altitude of 386 m above mean sea level), during the 2020/021-2021/022 growing seasons. The objective was to evaluate the effect of water deficit irrigation at different growth periods on yield, quality, and water productivity of sugarcane (Saccharum spp.) crops, under the central Sudan Agro-climatic zone. The test crop was the sugarcane Co 6806 variety, which occupies around 90% of cultivated areas. Central Sudan's agro-climatic zone climate is classified as semi-arid the maximum air temperature ranges from 31.6 to 43.7°C, the minimum air temperature ranges from 12.8 to 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 (GMA, 2021). The field experiment soil has been described as Remaitab series (subclass S2v) which is Smectitic alluvium, clayey Vertisols with moderate chemical fertility, low infiltration rate, bulk density was 1.5, brown in colour, quite uniform, and alkaline in reaction (pH paste 8.1). It contained about

49% clay, 18% silt, and 33 % sand with a saturation of 59%, field capacity (FC) of 38.5%, welting point (WP) of 22 % and available water content was 16.5.

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 7.5m) consisting of five ridges. The sugarcane variety was planted in November and harvested in February at the age of 15 months. The recommended package of practices was followed to raise the crop. 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 comprise two levels of water supply. The first was optimal irrigation (DT0) 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).

Table 1. The second deficit irrigation treatments conducted at eight growth periods as following

Deficit irrigation treatment	Age of sugar cane
DT1	Plant age 51th days to day100th
DT2	Plant age from day101th to day150th
DT3	Plant age from day151th to day 200th
DT4	Plant age from day 201th to day 250th
DT5	Plant age from day 251th to day 300th
DT6	Plant age from day301th to day 350th
DT7	Plant age from day 351th to day 400th
DT8	Plant age from day 401th age to day 450th

2.4. Local climate, crop, and soil data

The reference evapotranspiration (ET0) for the Guneid area was computed using the FAO-Penman-Monteith approach (Smith, 1991) and CROPWAT software. Seasonal actual evapotranspiration (ETa) and the irrigation required throughout the growing season were calculated according to the method described by Doorenbos and Kassam (1979). The seasonal amount of water requirement (CWR) for sugarcane crop was determined as a function of the local climate, crop, and soil data according to Doorenbos and Kassam (1979) as:

$$CWR = ET0 \text{ X } kc \tag{1}$$

Where CWR is crop water requirement (mm day^{-1}), ETo is evapotranspiration of a reference plant under specified conditions, calculated by the class A pan evaporation method (mm day^{-1}), and Kc is the crop 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 was determined by gravimetric method (Farbrother, 1973) at 20 cm to 60 cm depth using an auger and Tensiometer. The sampling was made one day before irrigation and three days after irrigation throughout the growing seasons.

2.5. Agronomic parameters

Cane 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 (ha^{-1}), stalk height(cm), stalk diameter (cm), number of nodes per stalk, and internodal length(cm) were recorded.

2.5.2. Cane quality

A representative sample of 10 millable canes from each plot was taken randomly, stripped, cleaned, and squeezed by an electric mill and the extracted juice was screened to determine the following traits according to Gamechis., and Vighneswara, (2020) to *ICUMSA., (1997)*:

Pol % cane: Sucrose percentage (Pol %), which was determined by using a Saccharimeter device.

Purity % cane: It is the ratio between sucrose percent and the corrected brix (total solids) value expressed as percent purity of juice and calculated by using the formula of *(Spancer and Meade.,1963)*.

$$\text{Cane juice purity (\%)} = \frac{\text{Pol \% Juice}}{\text{Brix \% Juice}} \times 100 \qquad (2)$$

Fiber content: Fiber was estimated at the time of harvest. Randomly selected, canes were cut into shreds with the help of shreds. 200 g pieces were weighed and taken in a bag and put under running water for 24 hours. After washing of all sugar, the remaining fiber was dried, weight was taken and the percent fiber was calculated by using the following formula.

$$\text{Cane fiber content \%} = \frac{\text{Dry weight of the washed shredded cane (g)}}{\text{Fresh weight of the shredded cane (200 g)}} \times 100 \qquad (3)$$

2.6. Water productivity (WP)

It means the irrigation production efficiency which is defined as the ratio of crop yield to seasonal irrigation water applied including rainfall (Howell, 1994), it was calculated by using the following equation:

$$WP=Y/SI \qquad (4)$$

Where WP is water productivity (kg $ha^{-1}m^{-3}$), Y is the yield (kg), and SI is the seasonal irrigation water applied including rain (m3).

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 (USDA, NRCS, March 2007 USDA).

3. Results and Discussion

3.1. Crop water requirements (CWR)

Table 1 showed the climatic data of the experimental area (Guneid area) then the seasonal amount of water requirement for sugarcane crops was determined in Table 2. Moreover, it showed results that indicated that the highest period of sugarcane water requirements at the grand growth stage ranged from 6.3 to 10.3 mm day^{-1}, followed by the development stage with 4.3 to 6.7 mm day^{-1}, the initial stage with 2.90 mm day^{-1} to 3.2 mm day^{-1} and late season stage with a value of 3.9 to 4.0 mm day^{-1} water requirements, respectively. Effective rainfall (Re) was recorded from June to September, the average ranged from 35.5 mm to 142 mm. Results also relieved that actual evapotranspiration (ET_a) reached a maximum value in March.

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 crop water requirements of the experimental area for two seasons

1st Season					2nd Season				
Month	**ET_0** (mm/day)	**k_c**	**CWR** (mm/day)	**Rainfall** (mm/month)	**Month**	**ET_0 (mm/day)**	**k_c**	**CWR** (mm/day)	**Rainfall** (mm/month)
Nov 2019	5.13	0.6	3.08	-	Nov 2020	5.47	0.6	3.28	-
Dec	4.81	0.6	2.90		Dec	4.94	0.6	2.96	-
Jan 2020	5.32	0.8	4.26	-	Jan 2021	5.02	0.8	4.02	-
Feb	6.10	1.1	6.71	-	Feb	5.96	1.1	6.56	-
Mar	7.31	1.3	9.50	-	Mar	7.93	1.3	10.31	-
April	7.73	1.2	9.28	-	April	7.80	1.2	9.36	-
May	7.93	1.0	7.93	-	May	7.74	1.0	7.74	10.3
June	9.74	1.0	9.74	-	June	8.08	1.0	8.08	40.0
July	7.25	1.0	7.25	33.5	July	6.30	1.0	6.30	58.7
Aug	4.90	1.0	4.90	142.0	Aug	5.74	1.0	5.74	79.6
Sept	5.70	1.0	5.70	15.5	Sept	5.36	1.0	5.36	47.4
Oct	6.00	0.9	5.40	-	Oct	5.30	0.9	4.77	-
Nov	5.40	0.8	4.00	-	Nov	5.02	0.8	4.02	-
Dec	4.90	0.8	3.92	-	Dec	5.00	0.8	4.00	-
Jan 2021	Dry off	-	-	-	Jan2022	Dry off	-	-	-
Annual	-	-	-	191mm	Annual	-	-	-	236mm

CWR is crop water requirement (mm day^{-1}), *ET*o is evapotranspiration (mm day^{-1}), and *K*c is crop water requirement coefficient for sugarcane.

3.2. Effect of water deficit on different growth periods of cane yield

Effects of deficit irrigation at the different growth periods on cane yield parameters were represented in Tables 3, 4, and 5 for the first crop cycle (plant cane). It was clear that deficit irrigation displayed a negative effect on sugarcane cane yield parameters stalk height (cm), stalk diameter(cm), intermodal length, stalk population, and cane yield (tc ha^{-1}) during the two growing seasons.

3.2.1. Stalk height (cm)

Stalk height decreased whereas plant cane age increased in which deficit irrigation treatments were applied until peak, data illustrated in Table 3. The highest reduction in stalk high recorded at DT_5 treatments. Statistical analysis showed that water deficit treatments affected significantly stalk height. Stalk height was reduced when water deficit irrigation was applied at all eight growth periods compared to the optimum irrigation treatment which obtained maximum stalk height (222 cm). Deficit irrigation during grand growth periods of sugarcane reduced rates of stalk elongation and internode length (DT_3, DT_4, and DT_5). Similar results were found when Zhao et al. (2010) applied water stress, they observed reduction rates of plant elongation and node increment and there is a close relationship between plant height and stem diameter.

3.2.2. Stalk diameter (cm)

Analysis of variance showed that water deficit treatments significantly reduced stem diameter due to water stress restricted photosynthesis, elongation, and lateral enlargement. Data shown in Table 3 the finding agreed with Silva and Costa (2004).

Table 3. Effect of water deficit at different growth periods on cane stalk height and stalk diameter.

Treatments	Stalk height (cm)			Stalk diameter (cm)		
	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean
DT_0	220.3^{a}	223.7^{a}	222.0	2.27^{a}	2.20^{a}	2.24
DT_1	211.0^{ab}	206.3^{abc}	208.7	2.02^{b}	2.20^{a}	2.11
DT_2	203.3^{ab}	206.3^{abc}	204.8	2.00^{b}	2.20^{a}	2.10
DT_3	198.7^{abc}	197.0^{abc}	197.9	1.90^{bc}	2.10^{a}	2.00
DT_4	179.3^{bc}	184.0^{bc}	181.7	1.70^{de}	2.10^{a}	1.90
DT_5	168.0^{c}	173.7^{c}	171.0	1.68^{e}	2.00^{a}	1.84
DT_6	184.0^{bc}	184.0^{bc}	184.0	1.73^{cde}	2.00^{a}	1.87
DT_7	181.7^{bc}	180.7^{bc}	181.2	1.73^{cde}	2.00^{a}	1.87
DT_8	201.0^{ab}	214.0^{ab}	207.5	1.87^{bcd}	2.20^{a}	2.04
Mean	194.2	196.0	195.1	1.87	2.10	1.99
CV%	9.49	9.9	-	5.60	6.20	-
LSD ($p \leq 0.05$)	31.91	33.6	-	0.18	0.23	-

Means sharing the same letters do not differ significantly at the 5% level of significance. DT0: Optimum irrigation, which was irrigated at 60% available soil moisture content (ASMC) at the root zone at all growing seasons. DT1 to DT8: Deficit irrigation treatments which were irrigated at 25% ASMC at the root zone at different growth periods.

3.2.3. Stalk population (1000ha^{-1})

Plant density is a major constituent of sugarcane yield. 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 the irrigation water. Water deficit treatments considerably decreased the sugarcane plant population compared with optimum irrigation treatment which produced an intensive plant population. The reduction of plant population when water deficit was applied to the sugarcane crop was probably due to a reduction in the number of tillers per plant. Zhao et al. (2010) reported that the water deficit reduced the number of tillers per plant. The reduction of the plant population in the second growing season was probably due to a reduction in total rainfall and the other climatic factors change (Table 1).

3.2.4. Internode length (cm)

The effect of Deficit irrigation application on intermodal length during 2020-21 and 2021-22 was significant (Table 4). The intermodal length significantly influences the yield of sugarcane. Optimal irrigation practice (DT_0 gave 10.8 and 9.5 cm intermodal length during the first and second seasons.

3.2.5. Stalk weight (kg)

Cane length displayed a positive correlation with one stalk weight and cane yield. No. of millable canes per hectare and yield are significantly correlated. Srivastava et al. (2005) found that the weight of one cane and cane yield were positively correlated. Table 5 showed that the effects of deficit irrigation on one cane stalk weight and total cane yield.

Table 4. Effect of water deficit at different growth periods on cane stalk population and intermodal length

Treatments	Stalk population (1000ha^{-1})			Internodal length (cm)		
	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean
DT$_0$	148.0^{a}	172.0^{a}	160.0	10.8^{a}	9.5^{a}	10.2
DT$_1$	135.0^{ab}	169.0^{a}	152.0	10.3^{a}	8.3^{ab}	9.3
DT$_2$	126.0^{cb}	166.0^{a}	146.0	10.0^{a}	8.5^{ab}	9.3
DT$_3$	119.0^{bcd}	152.0^{a}	135.5	10.1^{a}	8.1^{ab}	9.1
DT$_4$	105.0^{d}	147.0^{a}	126.0	8.4^{b}	8.1^{ab}	8.3
DT$_5$	102.0^{d}	142.0^{a}	122.0	8.6^{b}	7.7^{b}	8.2
DT$_6$	117.0^{cd}	162.0^{a}	139.5	9.7^{ab}	8.6^{ab}	9.2
DT$_7$	110.0^{cd}	158.0^{a}	134.0	9.6^{ab}	8.6^{ab}	9.1
DT$_8$	118.0^{cd}	164.0^{a}	141.0	10.2^{a}	9.2^{a}	9.7
Mean	119.0	157.0	138.0	9.7	8.4	9.1
CV%	8.20	11.7	-	8.3	8.9	-
LSD ($p \leq 0.05$)	17.0	32.0	-	1.39	1.3	-

Means sharing the same letters do not differ significantly at the 5% level of significance. DT0: Optimum irrigation, which was irrigated at 60% available soil moisture content at the root zone. DT1 to DT8: Deficit irrigation at first growth period to deficit irrigation at eighth growth period (from day one to day fifty after germination and from day 400th to day 450th). All these treatments were irrigated at 25% available soil moisture content at the root zone (ASMC).

3.2.6. Cane yield (tc ha^{-1})

There were significant differences in water deficit treatments on cane yield (Table 5 and Figure 1). DT$_0$ treatment recorded significant influence. The highest cane yield was (95.4 tc ha^{-1}), compared to DT$_4$, DT$_5$, and DT$_7$ treatments which recorded the lowest values of cane yield (81.4 tc ha^{-1}, 72.3 tc ha^{-1}, and 82.0 tc ha^{-1}) respectively, because high biomass crop requires large quantities of water for maximum production (Wiedenfed, 2008). Moreover, water stress reduced cane yield and dry weight of sugarcane (Basnayka et al., 2012). But DT$_6$ treatment recorded high values of cane yield (84.7 tc ha^{-1}) this is attributed to characterized of semi-arid regions during the rainy season by low temperatures, low evaporation rates, and high precipitation.

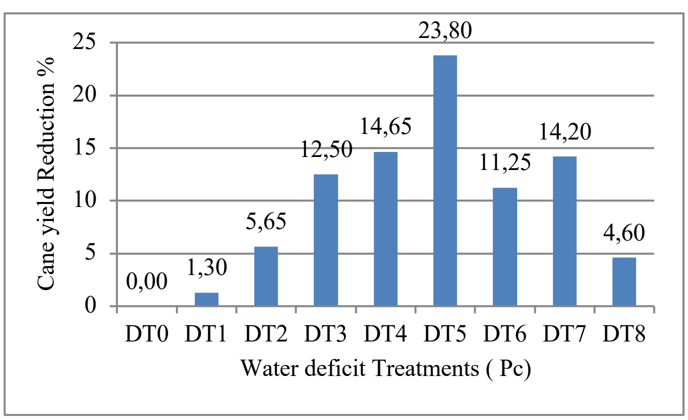

Figure 1. Effect of water deficit at different growth periods on cane yield reduction %, of two growing seasons (2020/021-2021/022).

3.3. Effect of water deficit at different growth periods on yield quality of cane plant

Tables 6, 7, and 8 showed the effects of deficit irrigation at different growth periods on yield quality parameters viz; Brix%, pol%, Purity%, Fiber%, ERS% cane, and Sugar yield (ts ha^{-1}), which affected by quality component. Moreover, water deficit negatively influenced sugarcane quality parameters. Control (DT_0) achieved the highest value of sugar yield (8.16) ts ha^{-1}. Furthermore, DT_8 recorded high in Brix% (16.1%), pol% cane (11.6%), ERS% cane (8.6%), and sugar yield values were (7.8 ts ha^{-1}) compared to DT_4, DT_5, and DT_7 treatments obtained the lowest values of sugar yield (6.55, 6.31, and 6.11 ts ha^{-1}, respectively). However, water deficits during the seven months of plant cane age (DT_1, DT_2, and DT_3 treatment) have significantly ($P \leq 0.05$) increased cane and sugar yield when compared to other treatments, this is attributed to the fact that deficit irrigation with the low level of water stress at tillering (DT_1, and DT_2, treatments) increase sugarcane plant numbers (Abdel-Wahab, 2005), while water deficit during the mid-season stage DT_4, and DT_5 were applied after fall significantly ($p \leq 0.05$) decreased cane and sugar yield compared to other treatments. This could mainly be because the mid-season stage is most sensitive to water stress (Eltayb, 2011). Deficit irrigation in the late season (DT_8) improves sugar cane quality and the crop is well ripened before harvest (Eltahir, 2002). But deficit irrigation before the drying off period after the rainy season has significantly ($p \leq 0.05$) decreased cane and sugar yield (DT_7), climatic data in Table 2 showed that in last October and November when deficit irrigation DT_7 was applied had high relative humidity % and high in evaporation(mm) that lead to a high reduction in sugar yield.

3.3.1. Total soluble solid (Brix% cane)

Total soluble solid is the main component determining the total sugar production. The deficit irrigation application method was failed to affect the brix % significantly. However, in the case of deficit irrigation treatments, brix % ranged from 16.42 to 16.10% during the first year and from 14.64 to 15.68% during the second year. These results agree with those of Jain et al. (2002) who reported that the quality of sugarcane did not vary. So that quality parameters such as brix and pol were not affected by cultural practices; Juice quality mainly depends on the genetic nature of the variety Wei and Eglinton (2022).

Table 5. Effect of water deficit at different growth periods on cane stalk weight and cane yield

Treatments	Stalk weight (kg)			Cane yield (ton ha^{-1})		
	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean
DT_0	0.84^{a}	0.95^{a}	0.90	84.5^{a}	106.3^{a}	95.4
DT_1	0.83^{ab}	0.79^{ab}	0.81	82.8^{ab}	105.7^{a}	Mean
DT_2	0.83^{ab}	0.77^{b}	0.80	79.4^{b}	100.7^{b}	90.1
DT_3	0.80^{ab}	0.72^{b}	0.76	74.4^{c}	92.3^{c}	83.4
DT_4	0.74^{abc}	0.66^{b}	0.70	72.1^{c}	90.7^{c}	81.4
DT_5	0.65^{c}	0.62^{b}	0.64	67.5^{d}	77.0^{d}	72.3
DT_6	0.71^{bc}	0.75^{b}	0.73	75.3^{c}	94.0^{c}	84.7
DT_7	0.66^{c}	0.64^{b}	0.65	72.9^{c}	91.0^{c}	82.0
DT_8	0.81^{ab}	0.79^{ab}	0.80	81.7^{ab}	100.0^{b}	90.9
Mean	0.75	0.74	0.75	76.7	95.3	86.0
CV%	9.17	13.7	-	2.6	2.08	-
LSD ($p \leq 0.05$)	0.96	0.18	-	3.4	3.44	-

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 at first growth period to deficit irrigation at eighth growth period (from day one to day fifty after germination and from day 400th to day 450th). All these treatments were irrigated at 25% available soil moisture content at the root zone (ASMC).

3.3.1. Sucrose content in cane (pol% cane)

The data on sucrose content in cane, as influenced by different deficit irrigation treatments, are presented in Table 6. Gross carbohydrate i.e. pol% is another most important sugar yield-determining factor and is totally controlled by the genetic makeup of a variety and climatic conditions. Weather factors prevailing during the maturity stage play a major role in the quality parameters of sugarcane (DT_8). Thus, deficit irrigation application treatments did not exhibit any influence on the pol %. In this case, DT_5 DT_6, DT_8, and DT_0 deficit irrigation treatments, showed a high value of sucrose content in comparison to the other deficit irrigation treatments. Pol percent ranged from 12.28 to 10.81% and11.28 to 10.17% in the first and second year, respectively. These results are in line with those of Eltayeb (2011**)** who reported that juice quality parameters such as sucrose were not affected by deficit irrigation treatments.

Table 6. Effect of water deficit at different growth periods on cane Brix% and on cane Pol%

Treatments	Brix% cane			Pol% cane		
	1stSeason	2ndSeason	Mean	1stSeason	2ndSeason	Mean
DT_0	16.31^{a}	15.49^{ab}	15.90	11.90^{ab}	11.23^{a}	11.59
DT_1	16.20^{a}	15.49^{ab}	15.85	11.52^{bcd}	10.50^{ab}	11.01
DT_2	16.10^{ab}	15.41^{ab}	15.76	11.85^{ab}	10.60^{ab}	11.23
DT_3	16.07^{ab}	15.12^{ab}	15.60	11.89^{ab}	11.08^{a}	11.49
DT_4	16.34^{a}	15.18^{ab}	15.76	11.57^{bc}	10.62^{ab}	11.10
DT_5	16.25^{a}	15.61^{ab}	15.93	12.28^{a}	11.26^{a}	11.77
DT_6	16.24^{a}	14.79^{ab}	15.52	11.93^{ab}	11.18^{a}	11.56
DT_7	15.38^{b}	14.64^{b}	15.01	10.81^{d}	10.17^{b}	10.49
DT_8	16.42^{a}	15.68^{a}	16.05	11.97^{ab}	11.28^{a}	11.60
Mean	16.14	15.27	15.71	11.65	10.77	11.21
CV%	2.92	3.83	-	3.53	4.18	-

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 at first growth period to deficit irrigation at eighth growth period (from day one to day fifty after germination and from day 400th to day 450th). All these treatments were irrigated at 25% available soil moisture content at the root zone (ASMC).

3.3.3. Purity (%)

The data pertaining to cane juice purity, as influenced by different deficit irrigation treatments, are presented in Table 7. The results revealed that the purity of cane juice was affected significantly by deficit irrigation application. Under different deficit irrigation treatments, cane juice purity % ranged from 81.28 to 90.72 and 87.15 to 79.9 during 2020-21 and 2021-22. The results showed that DT_0 and DT_8 treatment obtained the highest purity% values 87.70 and 88.94 as the mean of the two growing seasons. While DT_4, DT_5, and DT_7 recorded the lowest purity% values of 84.88, 80.59, and 83.76 respectively. So, this means that there was a significant association between cane yield and traits for juice parameters like purity%.

3.3.4. Fiber (%)

Genetically Fiber (%) is a controlled feature of the sugarcane crop. The fact that fiber percent was mainly controlled by varietal genetic makeup was proved and thus fiber was not affected significantly during each year of study. Table 7 showed there was no significant difference between different water deficit treatments on fiber% cane in the second season clearly. DT_0 treatment recorded the lowest fiber% cane values in the mean of two growing seasons (16.62%) while DT_5, DT_7, DT_4, and DT_3 achieved the highest fiber% values of cane (18.97, 18.74, 18.33, and 17.92) respectively. However, for deficit irrigation treatments, the fiber% ranged from 16.62 to 18.97. Adoption of full irrigation resulted in an improvement in cane juice quality which was reflected in the reduced cane fiber percent in comparison to deficit irrigation treatments.

Table 7. Effect of water deficit at different growth periods on Purity% in Juice and Fiber% in cane

Treatments	Purity (%)			Fiber (%)		
	1stSeason	2ndSeason	Mean	1stSeason	2ndSeason	Mean
DT_0	90.01^{ab}	85.38^{ab}	87.70	16.27^{d}	17.57^{a}	16.62
DT_1	87.62^{abc}	86.21^{ab}	86.92	16.80^{d}	17.83^{a}	17.32
DT_2	88.74^{ab}	82.42^{ab}	85.58	17.17^{cd}	18.20^{a}	17.69
DT_3	88.74^{ab}	85.40^{ab}	87.07	17.53^{bc}	18.30^{a}	17.92
DT_4	86.23^{bc}	83.53^{ab}	84.88	18.33^{ab}	18.33^{a}	18.33
DT_5	81.28^{d}	79.90^{b}	80.59	19.43^{a}	18.50^{a}	18.97
DT_6	88.34^{abc}	86.04^{ab}	87.19	17.03^{cd}	17.83^{a}	17.43
DT_7	84.36^{cd}	83.16^{ab}	83.76	19.00^{a}	18.47^{a}	18.74
DT_8	90.72^{a}	87.15^{a}	88.94	16.97^{cd}	17.83^{a}	17.40
Mean	87.34	84.36	85.85	17.62	18.10	17.86
CV%	2.66	4.71	-	3.76	4.96	-
LSD ($p \leq 0.05$)	4.03	6.88	-	1.15	1.55	-

Means sharing the same letters do not differ significantly at the 5% level of significance. DT0: Optimum irrigation, which was irrigated at 60% available soil moisture content at the root zone. DT1 to DT8: Deficit irrigation at first growth period to deficit irrigation at eighth growth period (from day one to day fifty after germination and from day 400th to day 450th). All these treatments were irrigated at 25% available soil moisture content at the root zone (ASMC).

3.3.5. Estimated recoverable sugar percentage (ERS%)

The results on estimated sugar recovery percentage clearly indicated that sugar recovery % was improved consistently during both the years of the study by treatments DT_0, DT_5, DT_6, and DT_8 compared to the other deficit irrigation, 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 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 year of investigation.

3.3.6. Sugar yield (ton ha^{-1})

Perusal of data on sugar yield as influenced by deficit irrigation treatments revealed significant differences between the treatments (Table 8 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 which gave a significantly higher sugar yield (8.16 ton ha^{-1}) in the mean of both two years.

3.4. Effect of water deficit at different growth periods on water productivity of cane plant

Table 10 shows the effect of deficit irrigation on cane water productivity. High values of water productivity were recorded when deficit irrigation treatments DT_1, DT_2, DT_3, and DT_8 were applied followed by DT_6, DT_0, DT_4, DT_7, and DT_5 respectively. Moreover, cane yield reduction was not significant when compared to the benefits of saved water. This result agreed with Ayana (2011), who reported that deficit irrigation saved significant irrigation water without significant yield losses.

Table 8. Effect of water deficit at different growth periods on ERS% and Sugar yield

Treatments	ERS (%) cane			Sugar yield (ton ha^{-1})		
	1st Season	2nd Season	Mean	1st Season	2nd Season	Mean
DT$_0$	8.90^{ab}	8.28^{a}	8.57	7.52^{a}	8.80^{a}	8.16
DT$_1$	8.52^{bc}	7.50^{ab}	8.01	7.05^{ab}	7.93^{b}	7.49
DT$_2$	8.85^{ab}	7.60^{ab}	8.23	7.03^{ab}	7.65^{b}	7.34
DT$_3$	8.89^{ab}	8.08^{a}	8.50	6.61^{bc}	7.46^{bc}	7.04
DT$_4$	8.57^{bc}	7.62^{ab}	8.10	6.18^{c}	6.91^{c}	6.55
DT$_5$	9.28^{a}	8.26^{a}	8.77	6.26^{c}	6.36^{c}	6.31
DT$_6$	8.93^{ab}	8.18^{a}	8.56	6.72^{b}	7.69^{b}	7.21
DT$_7$	7.81^{d}	7.17^{b}	7.50	5.69^{d}	6.52^{c}	6.11
DT$_8$	8.97^{ab}	8.23^{a}	8.63	7.33^{a}	8.23^{a}	7.78
Mean	8.68	7.77	8.68	6.71	7.50	7.11
CV%	4.36	5.81	-	5.53	6.46	-
LSD ($p \leq 0.05$)	0.66	0.78	-	0.63	0.83	-

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 at first growth period to deficit irrigation at eighth growth period (from day one to day fifty after germination and from day 400th to day 450th). All these treatments were irrigated at 25% available soil moisture content at the root zone (ASMC).

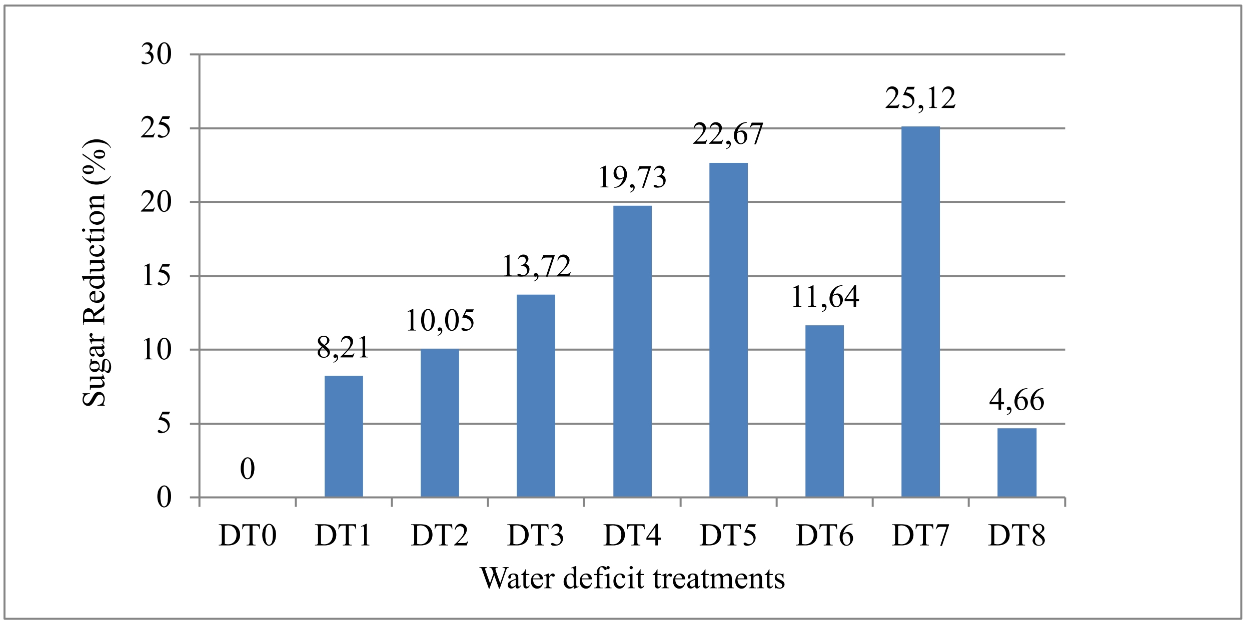

Figure 2. Effect of water deficit at different growth periods on plant cane sugar yield reduction %, mean of two growing seasons (2020/021-2021/022).

Table 9. Effect of water deficit on number of irrigations applied and water saved of plant cane at different growth Periods under Agro-Climatic zone (Sudan), seasons 2020/021- 2021-022.

Treatments	No. of irrigations applied	No. of Irrigations Saved	CWR $m^3(1000)\ ha^{-1}$/season	Water saved $m^3(1000)\ ha^{-1}$/season
DT_0 (control)	34	0	23.3	0.0
DT_1	31	3	20.2	3.1
DT_2	31	3	18.2	5.1
DT_3	31	3	19.2	4.1
DT_4	31	3	20.2	3.1
DT_5	31	3	20.9	2.4
DT_6	31	3	20.5	2.8
DT_7	31	3	21.4	1.9
DT_8	31	3	21.6	1.7
Mean	31.3	2.67	20.6	2.7

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 at first growth period to deficit irrigation at eighth growth period (from day one to day fifty after germination and from day 400th to day 450th). All these treatments were irrigated at 25% available soil moisture content at the root zone (ASMC).

Table 10. Effect of water deficit at different growth periods on water productivity of cane plant

Treat.	CWR $m^3(1000)\ ha^{-1}$			Total sugarcane kg (1000) ha^{-1}			Water productivity (WP) kg (1000) $ha^{-1}\ m^{-3}$		
	1st season	2nd season	Mean	1st season	2nd season	Mean	1st season	2nd season	Mean
DT_0 (control)	22.9	23.6	23.3	84.5 ^{a}	106.3^{a}	95.4	3.66	4.50	4.08
DT_1	20.1	20.2	20.2	82.8^{ab}	105.7^{a}	94.3	4.12	5.23	4.68
DT_2	17.9	18.4	18.2	79.4 ^{b}	100.7^{b}	90.1	4.42	5.48	4.95
DT_3	18.7	19.7	19.2	74.4 ^{c}	92.3^{c}	83.4	3.97	4.69	4.33
DT_4	19.6	20.8	20.2	72.1 ^{c}	90.7^{c}	81.4	3.69	4.36	4.03
DT_5	20.5	21.2	20.9	67.5 ^{d}	77.0^{d}	72.3	3.29	3.63	3.47
DT_6	20.0	21.0	20.5	75.3^{c}	94.0^{c}	84.7	3.75	4.48	4.12
DT_7	21.0	21.8	21.4	72.9 ^{c}	91.0^{c}	82.0	3.47	4.18	3.83
DT_8	21.2	22.0	21.6	81.7 ^{ab}	100.0^{b}	90.9	3.80	4.55	4.18
Mean	20.2	21.0	20.6	76.7	95.3	86.0	3.97	4.55	4.17
C.V %	-	-	-	2.6	2.08	2.34	-	-	-
LSD ($P \leq 0.05$)	-	-	-	3.4	3.4	3.4	-	-	-

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 at first growth period to deficit irrigation at eighth growth period (from day one to day fifty after germination and from day 400th to day 450th). All these treatments were irrigated at 25% available soil moisture content at the root zone (ASMC). Means sharing the same letters do not differ significantly at the 5 % level of significance. CWR: Crop water requirement.

Conclusion

Deficit irrigation treatments (DT1 to DT8) recorded a significant effect on cane and sugar yield reduction than the control (DT0) in the two seasons (2020/2021 and 20 21/2022) under Gunied conditions, Central Sudan Agro-climatic zone.

DT3, DT4, DT5, and DT7 treatments recorded significantly the highest cane yield reduction was 12.50 %, 14.65 %, 23.8 %, and 14.20 %. Sugar yield reductions were 13.70 %, 19.70%, 22.67%, and 25.12% respectively compared to DT0 with full Irrigation.

High Sugarcane water productivity was recorded at deficit irrigation treatments DT1, DT2, DT3, and DT8 respectively compared to optimum irrigation (DT0) as plant cane.

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