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Original article

Consecutive seasonal effect on yield and water productivity of drip deficit irrigated sorghum in saline soils

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ABSTRACT

Drought stress destructively affects the growth and productivity of sorghum crop, especially under saline soils. Therefore, Field trials were performed to determine the influence of water stress on water productivity (water productivity for grain, (G-WP) and water productivity for forage, (F-WP), yield of sorghum and soil properties in salt-affected soil (8.20 dS m^{-1}) under different sowing dates and irrigation regimes. The summer sowing (SS) was performed on 1 April while fall sowing (FS) was established on 2 August. The irrigation regimes were; 100, 90, 80, and 70% of crop evapotranspiration (ETc). The findings displayed that the fodder and grain yields were increased by 23% and 26% under SS compared to FS over the two seasons 2017 and 2018, respectively. Among irrigation levels, the maximum values of grain and fodder yield were given by 100% of ETc, while a non-significant difference was observed between 100% and 90% of ETc. Moreover, the maximum values of G-WP (1.31%) and F-WP (9.00%) were recorded for 90% of ETc. Interestingly, the soil salinity was decreased in 0–0.6 m depth, and more decline was noted in 0–0.2 m depth using 90% of ETc. The highest salt accumulation withinside the soil profile was recorded under 70% of ETc in comparison to 100% of ETc. Thereupon, under water scarcity, application of 90% of ETc is recommended with SS to save 10% of the applied irrigation water without a significant decrease in grain yield (GY).

1. Introduction

Sorghum (*Sorghum bicolor* L. *Moench*) is an essential cereal crop that is grown globally for feed and food demands. Over the world, it ranks as the sixth most planted crop after wheat, maize, rice, soybean, and barley (FAOSTAT, 2021). It is used not only for human consumption but also as fodder for animal feeding, building material, fencing, and brooms (Dahlberg et al., 2012). Egypt currently suffers from an intense scarcity of forage crops, specifically at the months of summer period. However, in Egypt, the annual cultivated area by forage crops beyond alfalfa plus silage plants about 296.8 × 10^3 ha, which approximately equals 10.3% from the whole planted area within the summer sowing (SS) and fall sowing (FS) periods. While, it cultivates 642.6 thousand hectares of winter forage crops, represents 22.2% from the cultivated winter crops area (El-Nahrawy, 2011). Sorghum is grown in the middle and upper parts of Egypt, and the total cultivated area under sorghum cultivation was 126 thousand hectares (Ezzat et al., 2010). Otherwise, the grain yield production of sorghum still lesser than the local consumption demands of Egypt (Abdel-Motagally, 2010). Soil salinity is abiotic stress that limiting both vegetative and reproductive

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development of grown crops (Shrivastava and Kumar, 2015; Semida et al., 2021a). Worldwide, about 800 million hectares of arable land classified as salt-affected soils (Shahid et al., 2018). Salinity stress dramatically restrict the agricultural productivity of grown crops particularly under hot-dry climatic conditions where precipitation is lower than evapotranspiration rates (Abd El-Mageed et al., 2020a; Abd El-Mageed et al., 2020b; Wang et al., 2011). Salinity causes ion toxicity, osmotic stress, nutrient deficiencies and ion imbalance, thereby the plants exposed to salinity stress are experiencing biochemical and physiological disruption, causing yield reduction of salinity-affected crops (Rady et al., 2016; Semida et al., 2021b; Desoky et al., 2020). Salinity induces significant decrease in seeds germination, growth of seedlings, grain yield and adversely impacts plant physiological and biochemical processes (Abd El-Mageed et al., 2018a; Abd El-Mageed et al., 2021). Sorghum could be classified as a moderate salt sensitive crop, but it sensitive to salinity at the stage of seedling emergence (Almodares and Sharif, 2007; Marsalis et al., 2010; Macharia et al., 1994). However, the response of sorghum against salt differs among the genotypes (Krishnamurthy et al., 2007; Bavei et al., 2011; Vasilakoglou et al., 2011). Water shortage is considered one of the main limiting factors which constrain plant growth and its existence in the natural ecosystem (Haden et al., 2012). Water withdrawal assessments around the world predict significant increases in water demand for industry, urbanisation, and other ecological sectors. Limited water availability decreased the chlorophyll contents, growth attributes, and yield of crops by disturbing the balance uptake of nutrients and water in the plants (Hussain et al. 2019; Kapoor et al. 2020). Therefore, water-soil management techniques and crop production practices must be established for increasing photosynthetic capacity (Abd El-Mageed et al., 2016; Ibrahim and Jaafar, 2011). Previously, it has been revealed that increased water productivity is beneficial in addressing the projected 40% gap between supply and demand to relieve water scarcity by 2030. This technique stays effective until stress conditions are severe or prolonged (Umar and Moinuddin, 2002). Deficit irrigation (DI) is valuable approach to save water by irrigating corps below their water necessities, but under which crops are exposed to a certain degrees of water stress either within a particular or the whole growth period (Pereira et al., 2002). Therefore, DI is a recommended practice to maximize the economic return under drought conditions (Attia et al., 2021). Farmers often grow sorghum under water shortage because it can tolerate drought stress, but the drought response of sorghum does not occur without a yield loss (Adzemi and Ibrahim, 2014). The effects of DI on the growth, development and productivity of several cultivated field crops have been extensively discussed (Ballester et al., 2014; Bell et al. 2018; Halli et al. 2021). Hence, it is important to examine the various effects of deficit irrigation under field conditions through different years, and determine the most suitable irrigation regime to be applied under specific location conditions for a given grown crop (Scholberg et al., 2000). Sorghum is sensitive to water scarcity during emergence, head initiation, booting, and flowering and grain filling stages. Water stress during vegetative development reduces the growth of stem and leaf area; it also shortens the length of the internodes and hence reduces plant height (Assefa et al., 2010; Rady et al., 2020). Drought stunts growth and inhibits crops to naturally develop and to complete a normal life cycle (Moussa and Abdel-Aziz, 2008; Rady et al., 2021). Therefore, this work aimed to estimate (1) the influence of DI schedules on grain and forage yields sorghum and WP under SS and FS (2) track the temporal changes in the electrical conductivity (ECe) within sorghum plant root zone.

2. Materials and methods

2.1. Experimental site

Field study was performed in a designated area for sorghum production at El Fayoum Governorate, Egypt (29° 35́ N, 31° 05́ E). Monthly metrological data during summer and fall as the average for two growing seasons are displayed in (Table 1). Soil samples were collected at two soil depth intervals of 0–30, 30–60 to analyze soil properties (Table 2). Soil of the experimental location is sandy loam in texture with electrical conductivity of 8.20 dS m^{-1}.

2.2. Experimental design

Split-plot statistical design with three replicates was implemented in this study. Randomly the main plots were allocated to examine sowing dates, meanwhile, the irrigation regimes were occupied the sub-plots. The experimental plots consisted of raised beds 16 m long and 0.9 m width (14.4 m^2) each raised bed included two planting rows with a distance of 0.5 m among rows and maintaining 0.2 m between plans within rows. Two drip lines were placed on each raised bed. The irrigation treatments were spaced by an alley of 3 m. The lateral diameter was 16 mm and emitters spaced 0.25 m apart with a flow rate of 4.0 L h^{-1}. All treatments were adequately irrigated during the period from the sowing date to one week after full germination. The characteristics of irrigation water are provided in Table 2.

2.3. Irrigation water applied (IWA)

The current investigation involved four irrigation treatments (i.e., 100, 90, 80 and 70% of the computed crop evapotranspiration using the evaporation pan method following as reported by Allen et al. (1998).

$$\mathrm{ETc} = \mathrm{Epan} \times \mathrm{Kpan} \times \mathrm{Kc} \tag{1}$$

where ETc: is the crop water requirement (mm day^{-1}); Epan: is the evaporation from the Class A pan (mm day^{-1}); Kpan: is the pan

Table 1
Monthly metrological data of Fayoum, Egypt throghout summer and fall as an average for two successive years (2017 and 2018).

Month	$^{\#}T_{max}$ (°C)	T_{min} (°C)	T_{avg} (°C)	RH_{avg} (%)	U_2 (m s^{-1})	E_p (mm d^{-1})
Summer sowing						
April	35.20	18.90	27.05	41.00	2.10	5.91
May	36.50	19.50	29.39	41.68	1.93	6.92
June	36.40	19.30	31.45	42.73	1.60	6.90
July	40.30	25.92	33.07	41.22	2.10	7.60
Fall sowing						
August	40.43	26.10	31.60	49.50	1.80	6.90
September	38.32	23.80	30.10	43.70	2.12	5.50
October	30.79	19.54	25.11	43.03	2.00	4.18
November	29.13	17.47	23.32	40.53	2.20	2.54

[#] T_{max}, T_{avg}, and T_{min} are average, maximum, and minimum temperatures, respectively, RH_{avg} is average relative humidity, U_2 is average wind speed, and E_P is average of measured pan evaporation class A.

Table 2
Some initial physicochemical characteristics of the studied soils and ionic composition for irrigation water.

Layer (cm)	ECe (dS/m)	pH	OM (%)	$CaCO_3$	Particle size distribution			Texture class	Bulk density ($g \cdot cm^{-3}$)	K_{sat} ($cm\ h^{-1}$)	Soil moisture content at		
					Sand (%)	Silt (%)	Clay (%)				FC (%)	WP (%)	AW (%)
0–30	8.22	7.63	1.03	4.31	77.15	11.20	11.65	LS	1.61	1.98	24.33	10.73	13.61
30–60	8.18	7.68	0.87	4.53	75.33	13.10	14.57	LS	1.56	1.65	24.19	12.13	12.06
Ionic composition for irrigation water													
Ionic concentration (meq./L)									EC ($dS\ m^{-1}$)		pH		SAR
CO_3^-	HCO_3^-	Cl^-	SO_4^-	Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^-					
0.00	2.35	11.73	5.92	5.34	4.84	8.4	1.42	0.00	1.97		7.44		5.28

LS = loamy Sand, FC = Field capacity, WP = Wilting point, AW = Available water, Ksat = Hydraulic conductivity, OM = Organic matter, EC means the electrical conductivity and SAR means sodium adsorption ratio.

coefficient (0.85), and Kc: is the crop coefficient according to Allen et al. (1998). Monthly means of relative humidity, wind speed and class A pan evaporation for growing periods during experimental SS (April, May, June, and July) and FS (August, September, October, and November) are presented in Table 1. The total crop growing period in summer (118 days) was slightly higher than that observed in the fall (114 days), but the required total water consumption at the summer growing period was (5078 $m^3\ h^{-1}$) higher than those consumed at FS (4079 $m^3\ h^{-1}$). Duration of various crop growth stages of sorghum crop by 20, 35, 40, and 30 days were assigned for initial, crop development, mid-season, and late-season stages, respectively, however, the values of Kc corresponding to the same growth periods were 0.7, 0.85, 1.10, and 0.55, respectively.

The quantity of irrigation water applied was computed by Abd El-Wahed and Ali, (2013) Eq. (2):

$$IWA = \frac{A \times ETc \times Ii \times Kr}{Ea \times 1000 \times (1 - LR)} \tag{2}$$

Where: IWA: is irrigation water applied (m^3), A: is irrigated plot area (m^2), ETc: is crop water consumption ($mm\ day^{-1}$), Ii: is intervals between irrigation (day), Kr: is coverage coefficient (Kr = (0.10 + Gc) $\leq$ 1) to Allen et al. (1998), Gc is ground cover, Ea: is the efficiency of application (%), and LR: is leaching requirements.

2.4. Management practices and measurements

Grains of sorghum (hybrid Horus) were sown on 1 April and 2 August and harvested on 29 July and 25 November for SS and FS respectively in both seasons 2017 and 2018. Grains were sown at 0.05-m away from the drip lateral at a planting depth of 0.04-m. The doses of chemical fertilizers were applied by 150, 60 and 70 kg ha^{-1} for N, P, K. elements respectively.

Stomatal conductance (Gs) was measured using a portable photosynthetic system (CIRAS-2, PP Systems, Hitchin, UK). Concentration of leaf chlorophyll was measured by SPAD502, KONICAMINOLTA. Inc., Tokyo. Chlorophyll fluorescence (F_v/F_m) was determined using Handy PEA, Hansatech Instruments Ltd, Kings Lynn, UK, as described by Maxwell and Johnson (2000) and Spoustova et al. (2013). The PI was estimated by Clark et al. (2000) method. The relative water content (RWC %) of the fully expanded fresh leaf was measured by Hayat et al. (2007) method. MSI was measured, as mentioned by Rady (2011). At harvest, randomly five individual plants were collected from every cultivated plot then prepared to measure stem diameter, 1000 grain weight; however, leaf area per plant was digitally measured by a planometer (Planix 7).

2.5. Water productivity (WP)

Water productivity of sorghum for grain and forage yields expressed according to Jensen et al. (1990) Eq. (3):

$$WP = \frac{Grainorforagesorghumyield(kgha^{-1})}{Irrigationwater(m^3ha^{-1})} \tag{3}$$

2.6. Soil sampling

To monitor the variation in soil electrical conductivity (ECe) within the soil domain during the experimental period 15 observation points were set for the collection of soil samples. These observation points were fixed in vertical direction at five depths, i.e., 0–0.1, 0.1–0.2, 0.2–0.3, 0.3–0.4, and 0.4–0.5 m and situated at three horizontal distance 10 cm apart beginning from the left edge of experimental domain. The collected soil samples prepared and mixed with distilled water to saturation. The solution was extracted from saturated samples then (ECe) of the soil- extract measured by a digital instrument (model 3200, YSI, Inc., Yellow Springs, Ohio).

2.7. Statistical analysis

The obtained data for each variable were analyzed using ANOVA procedures by GenStat statistical package (12th Ed., VSN International Ltd., Oxford, U.K.). In case of significant effects, the treatments means were separated using Duncan's new multiple range test at $P \leq 0.05$ probability level.

3. Results

3.1. Morphological and yield traits of sorghum

Plant height, leaves area $plant^{-1}$, stem diameter $plant^{-1}$, and 1000 grain weight were affected significantly by sowing date, IWA, and their interaction (Table 4). The maximum values of plant height (167.41 cm), leaves area $plant^{-1}$ (119.31 cm^2), stem diameter $plant^{-1}$ (2.16 cm), and 1000 grain (30.03 g) were recorded in SS, while the minimum values of corresponding traits (149.26 cm, 112.20 cm^2, 1.98 cm, and 26.39 g) were recorded in FS. On average, the highest values of plant height (170.91 cm), leaf area $plant^{-1}$ (130.31 cm^2), stem diameter (2.30 cm), and 1000-grain weight (31.07 g) were recorded for $I_{100\%}$. Drought stress gradually decreased the aforementioned parameters. Grain (GY) and forage yields (FY) were affected significantly by sowing date, IWA and their interaction (Table 3). The summer sowing (SS) produced higher values of the abovementioned aspects relative to fall sowing (FS). The GY was remarkably increased by 23.72 and 22.44% under SS relative to FS respectively, in both growing seasons. Likewise, FY was increased by 25.29 and 26.88% under SS compared to FS in two seasons, respectively. In addition, the highest values of GY and FY were observed under well-watered treatment than those under drought stress conditions. However, it was observed that water

Table 3

Effect of sowing date (SD) and deficit irrigation on growth characteristics of sorghum plants in 2017 and 2018 seasons (means ± SE).

Treatment	Plant height (cm)	Leaves area (cm^2)	Stem diameter plant^{-1} (cm)	1000 grain weight (g)	Grain yield (t ha^{-1})	Forage yield (t ha^{-1})
2017						
SD	**	**	**	**	**	**
SS	164.51 ± 3.1^{a}	115.91 ± 3.9^{a}	2.12 ± 0.06^{a}	29.33 ± 0.99^{a}	5.32 ± 0.23 ^{a}	35.77 ± 1.9^{a}
FS	145.11 ± 3.1^{b}	108.70 ± 3.5^{b}	1.95 ± 0.09^{b}	26.08 ± 0.78^{b}	4.30 ± 0.19^{b}	28.55 ± 2.1^{b}
DI	**	**	**	**	**	**
DI $_0$	167.61 ± 5.4^{a}	126.22 ± 2.6^{a}	2.25 ± 0.02^{a}	30.33 ± 1.1^{a}	5.52 ± 0.15^{a}	38.60 ± 1.7^{a}
DI$_{10\%}$	164.70 ± 5.2 ^{a}	119.60 ± 2.2^{b}	2.19 ± 0.02^{a}	30.17 ± 0.87^{a}	5.31 ± 0.33^{a}	36.90 ± 2.0^{a}
DI$_{20\%}$	154.92 ± 4.7^{b}	109.80 ± 0.33^{c}	2.06 ± 0.06^{b}	27.00 ± 0.58^{b}	4.70 ± 0.22^{b}	31.59 ± 1.3^{b}
DI$_{30\%}$	133.31 ± 1.9^{c}	93.61 ± 1.9^{d}	1.64 ± 0.08^{c}	23.33 ± 0.61^{c}	3.71 ± 0.23^{c}	21.56 ± 1.5^{c}
SD × DI	**	*	*	*	**	**
2018						
SD	**	**	**	**	**	**
SS	170.33 ± 5.1^{b}	122.71 ± 4.5^{a}	2.19 ± 0.06^{a}	30.73 ± 0.92^{a}	5.51 ± 0.26^{a}	36.87 ± 1.8^{a}
FS	153.42 ± 3.6^{c}	115.17 ± 3.9^{b}	2.01 ± 0.09^{b}	26.70 ± 1.11^{b}	4.50 ± 0.21^{b}	29.06 ± 2.1^{b}
DI	**	**	**	**	**	**
DI $_0$	174.20 ± 4.4^{a}	134.42 ± 2.8^{a}	2.35 ± 0.01 ^{a}	31.81 ± 0.82^{a}	5.81 ± 0.24^{a}	39.80 ± 1.5^{a}
DI$_{10\%}$	171.30 ± 4.3^{a}	127.30 ± 2.3^{b}	2.26 ± 0.02^{b}	31.74 ± 0.99^{a}	5.48 ± 0.21^{a}	37.24 ± 1.5^{a}
DI$_{20\%}$	160.22 ± 5.3^{b}	116.40 ± 0.54^{c}	2.12 ± 0.06^{c}	27.89 ± 0.72^{b}	4.86 ± 0.35^{b}	32.11 ± 2.1^{b}
DI$_{30\%}$	138.21 ± 1.6^{c}	97.81 ± 1.6^{d}	1.67 ± 0.08^{d}	23.42 ± 1.11^{c}	3.86 ± 0.12^{c}	22.90 ± 1.5^{c}
SD × DI	**	*	**	*	*	**

** and * denote significant differences at ($p \leq 0.05$ and $p \leq 0.01$) probability level; ns denotes non-significant difference. All means tracked by the similar letter for each column are not differed significantly based on the LSD test ($p \leq 0.05$).

stress had a detrimental impact on yield production; GY and FY (Table 3). On average, the maximum records for GY and FY (5.67 and 39.20 t ha^{-1}) were obtained under DI$_{100\%}$, however the lowest estimations of GY (3.79 and 22.23 t ha^{-1}) were recorded under DI$_{70\%}$ in the two growing seasons, respectively. Increasing drought stress regimes (DI$_{80\%}$ and DI$_{70\%}$) was associated with a decline in yield components. As illustrated in Table 3, the differences between DI$_{90\%}$ and DI$_{100\%}$ in GY (5.40 and 5.67 t ha^{-1}) and FY (38.07 and 39.20 t ha^{-1}) were non-significant. Consequently, under limited water, it could be applying DI$_{90\%}$, and save 10% of supplied irrigation water and producing, approximately, the same GY and FY. Saving the applied irrigation water by 10, 20 and 30% caused reduction in GY by 4.77, 15.62, and 33.19% as well as FY by 5.43, 18.75, and 43.29% compared with DI$_{100\%}$, respectively.

3.2. Plant water relations and physiological responses

Data presented in Table 4 cleared that plant water relations, and physiological responses (RWC%, MSI, Gs, SPAD, Fv/Fm, Fv/F0, and PI) significantly affected by the sowing date, IWA and their interaction. On average, the highest values of RWC (79.77%), MSI (64.78%) Gs (390.18), SPAD (52.04), Fv/Fm (0.82), Fv/F0 (3.87) and PI (4.21) were recorded under SS compared to 76.83% and 61.82%, 309.73, 50.21, 0.80, 3.75 and 3.53 respectively, under FS in both seasons. Concerning IWA, data outlined in Table 4 clarified that except for chlorophyll fluorescence (Fv/Fm), Gs, SPAD, Fv/F0, PI, RWC % and MSI were differed significantly and increased in parallel with increasing IWA. The highest values of plant water relations and physiological responses RWC (87.11%), MSI (70.02%), Gs (473.47), SPAD (60.18), Fv/F0 (4.59) and PI (4.74) were recorded under I$_{100\%}$ treatment while the lowest ones (61.24%, 54.26 %181.38, 37.00, 2.81 and 2.43) were recorded under DI$_{70\%}$ treatment, in both seasons. The reduction in the above-mentioned traits under irrigation treatment I$_{90\%}$ was non-significant as compared with control I$_{100\%}$.

3.3. Sorghum productivity and G-WP and F-WP

G-WP and F-WP values (data not shown) were significantly differed as a result of applied sowing date, IWA, and their interaction. The highest values of G-WP and F-WP (1.25 and 8.41 kg m^{-3}) were observed for SS (1.27 and 8.31 kg m^{-3}) compared to FS treatments. This result due to the GY and FY obtained under SS treatments (5.42 and 36.32 t ha^{-1}) was higher than the GY and FY produced under FS treatments (4.40 and 28.81 t ha^{-1}) by 23.07 and 26.09%, respectively. Concerning the effect of IWA, the average, the maximum G-WP, and F-WP (1.31 and 9.00 kg m^{-3}) values were recorded for DI$_{90\%}$ relative to (1.18 and 6.93 kg m^{-3}) for DI$_{70\%}$. The relationships between WP and GY, and FY during the studied two sowing dates were described as curvilinear (polynomial of second-order (Fig. 1). These relationships can be represented according to the following equations:

4. In SS season

$$FY = -3E^{-09} \times IWA^3 - 3E^{-05} \times IWA^2 - 0.0984 \times IWA + 93.05 \quad R^2 = 1$$

$$F\text{-}WP = -3E^{-10} \times IWA^3 + 2E^{-06} \times IWA^2 + 0.0022 \times IWA - 9.2 \quad R^2 = 1$$

$$GY = 1E^{-09} \times IWA^3 - 2E^{-05} \times IWA^2 + 0.0795 \times IWA - 115.94 \quad R^2 = 1$$

$$G\text{-}WP = 4E^{-10} \times IWA^3 - 5E^{-06} \times IWA^2 + 0.0223 \times IWA - 31.521 \quad R^2 = 1$$

5. In FS season

$$FY = 1E^{-08} \times IWA^3 - 0.0001 \times IWA^2 + 0.524 \times IWA - 634.43 \quad R^2 = 1$$

$$F\text{-}WP = 5E^{-09} \times IWA^3 - 5E^{-05} \times IWA^2 + 0.193 \times IWA - 227 \quad R^2 = 1$$

$$GY = -3E^{-09} \times IWA^3 + 3E^{-05} \times IWA^2 - 0.0902 \times IWA + 100.71 \quad R^2 = 1$$

$$G\text{-}WP = -7E^{-10} \times IWA^3 + 8E^{-06} \times IWA^2 - 0.025 \times IWA + 28.99 \quad R^2 = 1$$

Where: F-WP and G-WP are water productivity of forage and grain yield of sorghum (kg m^{-3}) and IWA is applied irrigation water (m^3).

5.1. Salt distribution pattern

The experiment was conducted in saline soil (ECe = 8.2 dS m^{-1}) and the used water for irrigation (ECiw = 1.97 dS m^{-1}, SAR = 5.28) falls under the second category for salinity and sodicity levels (C2S1, ECiw = 0.75–3.00 dS m^{-1} and SAR < 6.0). There were significant differences among initial soil ECe (Table 2) and after treat-

Table 4
Effect of sowing date and deficit drip irrigation on physiological responses (stomatal conductance (Gs) and SPAD), photosynthetic efficiency (F_v/F_m, F_v/F_0 and PI) and plant water status (RWC and MSI %) of sorghum plants in 2017 and 2018 seasons (means ± SE).

Treatment	Gs	SPAD	Fv/Fm	Fv/F_0	PI	RWC (%)	MSI (%)
2017							
SD	**	*	**	**	**	**	**
SS	392.72 ± 18.3^{a}	51.04 ± 3.1^{a}	0.81 ± 0.01^{a}	3.76 ± 0.22^{a}	4.19 ± 0.3^{a}	78.69 ± 0.51^{a}	63.58 ± 1.8^{a}
FS	312.61 ± 19.3^{b}	49.54 ± 2.4^{b}	0.79 ± 0.01^{b}	3.63 ± 0.23^{b}	3.41 ± 0.2^{b}	76.51 ± 0.43^{b}	60.78 ± 1.9^{b}
DI	**	**	**	**	**	**	**
DI_{0}	473.50 ± 15.0^{a}	59.33 ± 0.57^{a}	0.83 ± 0.00^{a}	4.47 ± 0.02^{a}	4.64 ± 0.2^{a}	86.77 ± 0.51^{a}	68.54 ± 0.76^{a}
$\mathrm{DI}_{10\%}$	432.11 ± 14.5^{b}	56.88 ± 0.86^{a}	0.82 ± 0.00^{a}	4.36 ± 0.06^{a}	4.52 ± 0.3^{a}	85.39 ± 0.43^{a}	67.47 ± 0.68^{a}
$\mathrm{DI}_{20\%}$	319.31 ± 14.3^{c}	48.92 ± 1.2^{b}	0.80 ± 0.01^{b}	3.28 ± 0.05^{b}	3.66 ± 0.1^{b}	76.99 ± 1.1^{b}	59.03 ± 0.20^{b}
$\mathrm{DI}_{30\%}$	185.54 ± 9.6^{d}	36.03 ± 0.96^{c}	0.76 ± 0.01^{c}	2.69 ± 0.02^{c}	2.37 ± 0.1^{c}	61.24 ± 0.88^{c}	53.67 ± 1.4^{c}
SD × DI	**	**	NS	*	**	*	**
2018							
SD	**	**	**	**	**	**	**
SS	387.64 ± 18.9^{a}	53.04 ± 3.2^{a}	0.82 ± 0.01^{a}	3.98 ± 0.23^{a}	4.23 ± 0.3^{a}	80.85 ± 2.3^{a}	65.98 ± 1.7^{a}
FS	306.84 ± 20.8^{b}	50.88 ± 2.3^{b}	0.8 ± 0.01^{b}	3.86 ± 0.22^{b}	3.64 ± 0.3^{b}	77.14 ± 2.7^{b}	62.86 ± 2.3^{b}
DI	**	**	**	**	**	**	**
DI_{0}	473.43 ± 22.1^{a}	61.03 ± 1.1^{a}	0.83 ± 0.01^{a}	4.71 ± 0.07^{a}	4.83 ± 0.2^{a}	87.44 ± 0.76^{a}	71.50 ± 0.53^{a}
$\mathrm{DI}_{10\%}$	428.84 ± 17.3^{b}	58.43 ± 0.95^{a}	0.82 ± 0.01^{b}	4.55 ± 0.02^{b}	4.73 ± 0.2^{a}	84.56 ± 0.93^{a}	69.04 ± 0.67^{a}
$\mathrm{DI}_{20\%}$	309.34 ± 14.3^{c}	50.42 ± 0.95^{b}	0.81 ± 0.00^{c}	3.48 ± 0.02^{c}	3.82 ± 0.1^{b}	77.99 ± 0.25^{b}	62.28 ± 0.18^{b}
$\mathrm{DI}_{30\%}$	177.21 ± 10.3^{dc}	37.97 ± 0.85^{c}	0.77 ± 0.00^{d}	2.93 ± 0.04^{d}	2.48 ± 0.1^{c}	61.24 ± 1.5^{c}	54.85 ± 1.8^{c}
SD × DI	**	**	*	*	*	**	**

** and * denote significant differences at ($p \le 0.05$ and $p \le 0.01$) probability level; ns denotes non-significant difference. All means tracked by the similar letter for each column are not differed significantly based on the LSD test ($p \le 0.05$).

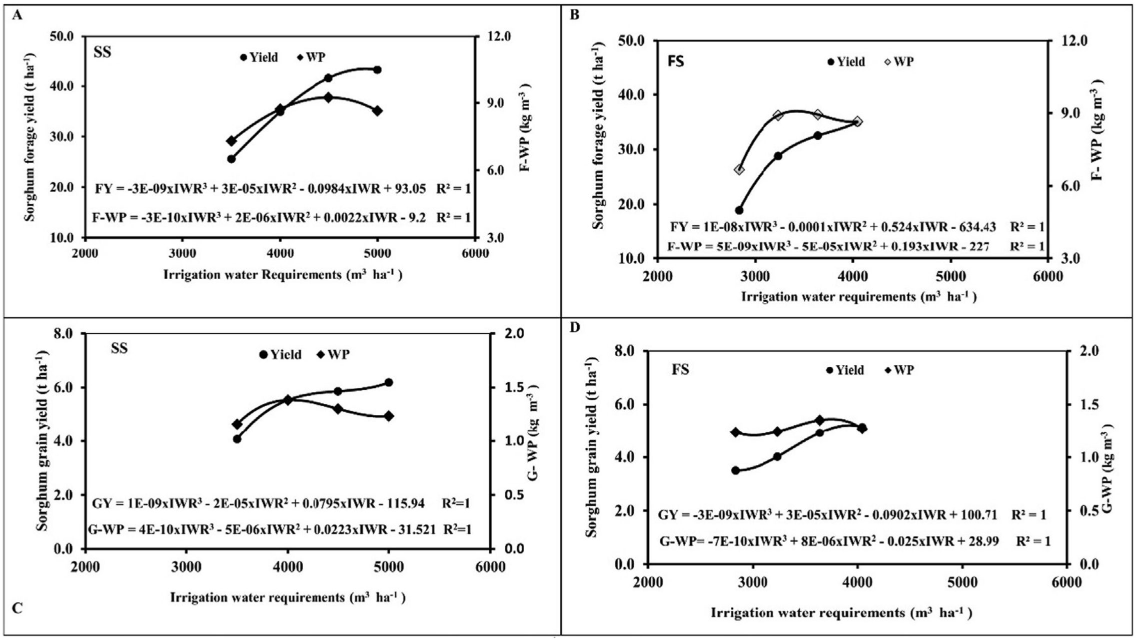

Fig. 1. Sorghum regression analysis between forage yield, (A and B) grain yield (C and D), IWA, F-WP and G-WP summer-fall deficit drip irrigation. As average for two successive years (2017 and 2018).

ments (Fig. 2). Under all IWA application rates, the ECe increased as the distance increased from the situated dripper lines to the fringes of the wetted area. Based on the measured soil ECe within the soil domain, it was observed that the migration of soil salts was associated with the flow direction of irrigation water to be accumulated surrounding the drippers in all directions. Soil salinity (ECe) decreased at depth 0.0–0.5 m, while the distribution pattern and reduction percentage of these concentrations of soil salts were varied gradually between the studied soil layers. The high reduction occurred at soil layer 0.0–0.10 m, which more than those investigated at 0.1–0.20, 20–30, 30–40 and 0.4–0.5 m depths. In addition, the observed decrease of ECe was greater under control ($I_{100\%}$) compared to DI treatments (Fig. 2). Moreover, (Fig. 2) illustrate the accumulation of ECe within soil depth (0–0.50 m). The highest accumulation of ECe was observed at $DI_{70\%}$ which could be responsible on the sever reduction in grain and forage yield of sorghum (3.79 and 22.23 t ha^{-1}) in 2017 and 2018 seasons, respectively relative to the other applied irrigation regimes. On the other hand, the greatest IWA value ($DI_{100\%}$) increased water availability resulting higher dilution for salt- solutions, accordingly better response and higher grain and forage yield of sorghum plants (5.67 and 39.20 t ha^{-1}) in 2017 and 2018 seasons, respectively.

6. Discussion

Water deficiency is the key factor challenges the sustianability of agricultural system in arid and semiarid regions (Misra, 2014). Drought, salinity, and heavy metals are the most abiotic stress factors that drastically restrict the growth and productivity of grown crops worldwide (Desoky et al., 2020a,b; Ma et al., 2020). Further-

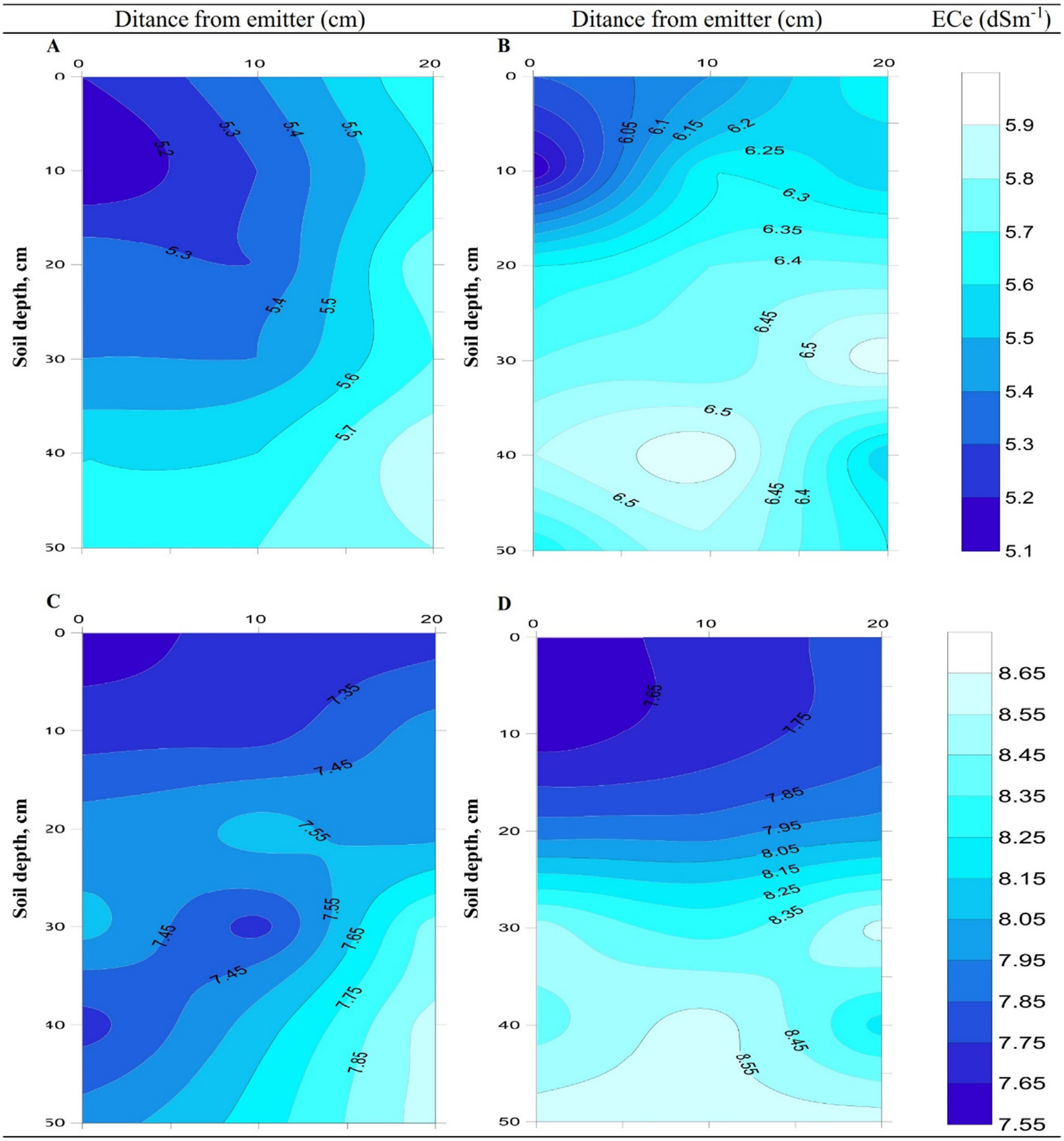

Fig. 2. The salt distribution pattern (ECe dS m^{-1}) within the vertical transects perpendicular drip line after treatments for control $I_{100\%}$ (A), $DI_{90\%}$ (B), $D_{I80\%}$ (C) and $DI_{70\%}$ (D) irrigation treatments, respectively. As average for two successive years (2017 and 2018).

more, soil degradation caused by salinity, suppressing crop production. Consequently, its important to decrease the detrimental effects of salinty and drought on growth of grown crops and improve water productivity by efficient utilization of the limited water resources. Deficit irrigation (DI) as an efficient irrigation method for enhancing water use efficiency and economic return of grown crops should be precisely applied to eliminate yield reduction induced by drought or salinity (Abd El-Mageed et al., 2018b).

Our results demonstrated that the morphological attributes of sorghum plants were adversely influenced by water shortage (Table 4). DI leads to diminish cell elongation, decrease in cell size and leaf area. This decrease may be associated to reduced water and nutrients uptake under water deficit that causes lack of cell turgor and metabolic inhibtion, consequently reduction in growth rate of sorghum plants (Sadak et al., 2020). The negative impact induced by drought on sorghum at the seedling stage, and drought restrained shoot growth than roots was reported by Mirbahar et al. (2009), Abd El-Mageed et al. (2018a), (Attia et al., 2021). Furthermore, grain yield and forage yield of sorghum plants were inhibited by water stress (Table 4). The decrease in GY of various crops under deficit irrigation treatments may be refer to declined soil water content that has been led to delay plant rooting (Bathke et al., 1992) and consequently a decrease in leaf area, root system, and decrease in photosynthesis activities (Masle and Passioura, 1987). This is in agreement with the findings of Abd El-Wahed et al. (2017). Therefore, it could be speculated that achieving sufficient water content in the root zone under $DI_{100\%}$ contributed to an increase in water and nutrients' uptake. Hence, stimulation in plant metabolic activates and consequently increase in plant growth attributes (height, leaves area plant^{-1}, stem diameter plant^{-1}, 1000-grain weight, FY, leading and GY (Abd El-Wahed and Ali, 2013).

Similarly, our results showed nigative impact induced by water stress on plant water relations and physiological responses (Table 4). The decrease in RWC% might be a result of some dehydration in protoplasm under water dificit. In addition water stress generates the production of reactive oxygen species (ROS) causing lipid oxidation and membrane injury, accordingly, decrease in cell membrane stability MSI%. Under water deficit, stomatal conductance, photosynthesis, and different physiological process become reduced. The declines in both RWC% and MSI% were correlated with lower Gs and photosynthetic rates. Decreases in Fv/Fm and PI under water deficit may be caused due to the reduction of cell expansion that inhibiting leaf elongation and leaf area (Basu et al. 2016), accordingly lower photosynthetic efficiency and leaf photosynthetic pigments. Similar impact was elucidated by Amer, (2011), Habibi, (2012), Abd El-Mageed et al. (2016). The decrease in chlorophyll concentrations as a result of osmotic stress may refer to the strong destruction and damage of chloroplast cells (Kaiser et al., 1981; Abd El-Mageed and Semida, 2015). The decline in photosynthetic performance under water shortage was detected by Habibi, (2012), Ahmed et al. (2009) and Abd El-Mageed et al. (2017). These investigations concluded that there is a significant association between Fv/Fm and gs because a decline in stomatal closure reduces the availability of CO_2 for dark response under DI-stressed regimes. Moreover, water deficit may create a similar decrease in photosynthesis rate as the result of the negative effect on photochemical and metabolic activities in the leaf, and on closure of stomatal system, therefore, decrease in the area of leaf surface (Dejong, 1996).

Enhancing water productivity for irrigated crops could be achieved by maintaining relatively higher crop yields corresponding to the applied irrigation water. In current investigation, the maximum G-WP, and F-WP observed for DI at 90% of ETc (Fig. 1). Under slight water deficit regime as $DI_{90\%}$, when minor stomata closure occurs, then the decrease in transpiration is more than the rate of photosynthesis and, accordingly increases in Y-WP. These obtained results are in line with those of Wang et al. (2011), Liu et al. (2013) and El-Samnoudi et al. (2019). They observed a higher Y-WP was given under moderate level of water stress then decreased with increasing severity of water stress. Conversely, the high intense of drought may cause full closure of stomatal system that leads to a drastic decrease in Y-WP and yield (Chen et al., 2009).

Salinity distribution through soil profile was controlled by the redistribution of soil moisture under each irrigation regime. Our results as presented in (Fig. 2) concluded that, under all IWA application rates, the ECe raised as the distance increased from the situated dripper lines to the fringes of the wetted area. The migration of soil salts was associated with the flow direction and flow rate of irrigation water to be accumulated surrounding the drippers in all directions. The larger amount of applied irrigation water under control ($I_{100\%}$) increase the leached salts away from drip lines compared to the other DI treatments. Therefore, the decrease in salt concentrations near the dripper lines is meaning a decrease in osmotic stress on the grown plants (Chen et al., 2010). Therefore, drip irrigation can be considered a good technique for decreasing salinity stress on the growth of plants. This is in consonance with Abd El-Wahed et al. (2020) and Abd El-Mageed et al. (2019). These results could be attributed to more water availability in the root zone at $DI_{100\%}$ level in corresponding to $DI_{70\%}$ regime, consequently reduction in soil salinity in the surface soil layer. However, the obtained result in parallel with the results of Abd El-Mageed et al. (2019).

7. Conclusions

Results of two successive seasons showed that the GY and FY were increased by 23.08 % and 26.08% under SS compared to FS in 2017 and 2018 seasons, respectively. With increasing, deficit irrigation from $DI_{100\%}$ to $DI_{70\%}$, grain yield and forage yield reduced by 33.19%, and 43.29%, respectively. On average, the greatest values of G-WP (1.31 %) and F-WP (9.00%) were recorded under $DI_{90\%}$. After two seasons of experimentation, it is reasonable to conclude that the reductions in ECe at the 0–10 cm depth were greater than those in the 20–30, 30–40 and 40–50 cm levels. When the soil salinity of the deep soil layer (0–50 cm) was compared to the soil salinity of the other treatments, the $I_{100\%}$ treatment had a stronger influence on the soil salinity of the deep soil layer (0–50 cm) than the other treatments. As a result, when irrigation water is limited, it is recommended that sorghum plants be irrigated at a rate of $I_{90\%}$ of ETc% to produce nearly the same yields while saving more water than if they were irrigated at a rate of $I_{100\%}$ of ETc%.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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