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Compost and mulching modulates morphological, physiological responses and water use efficiency in sorghum (bicolor *L. Moench)* under low moisture regime

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ABSTRACT

Supplying organic compost and mulching could be a practical solution to alleviate the negative effects of water stress on sorghum (bicolor *L. Moench*) in newly reclaimed soils. For this purpose, two field experiments were conducted during 2016 and 2017 seasons. This investigation was conducted as split-split experiments based on randomized complete blocks design with organic compost (OC) as a soil amendment at three levels (0, 15 and 30 t ha^{-1}), rice straw as a soil mulching (M) at two levels (0, and 10 t ha^{-1}) and soil moisture at three levels (100, 85 and 70% of ETc) using three replications. Sorghum yields (forage and seed), and forage and seed water use efficiencies (F-WUE and S-WUE) were significantly ($P < 0.05$) affected by irrigation quantity and by both compost and mulching application. Plant growth (e.i. plant height, shoot dry, and leaf area), leaf photosynthetic pigments, plant water status (canopy temperature, relative water content (RWC%), and harvest index (HI) were also significantly ($P < 0.05$) affected in two seasons. The highest yields (41.41 and 7.8 t ha^{-1} for forage and seed yields) as the average for both seasons were recorded under full irrigation, 10 t ha^{-1} of M and 30 10 t ha^{-1} of OC. It can be concluded that organic compost and soil mulching improved significantly seed and forage yield production under deficit irrigation conditions. The results indicate that under scarcity water, application of ($I_{85} \times OC_{30} \times M_{10}$) treatment was found to be favorable to save 15% of the applied irrigation water, to produce not only the same yields, approximately, but also to save more of water as compared to $I_{100\%}$.

1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is the fifth most important cereal crop in the world after wheat, maize, rice, and barley (FAO STAT, 2012). Sorghum is an important annual cereal crop grown for both grain and palatable green forage production. Additionally to sorghum as a food crop, there are possibilities of other alternative uses of sorghum such as feed for dairy animals, novel foods, industrial uses, processed foods starch, beverages and ethanol (Taylor et al., 2006).Fresh water scarcity has become a worldwide serious problem, especially in arid and semi-arid area where irrigation is essential for crop production (Wei et al., 2016). Agricultural irrigation is vital to food production in many parts of the globe and a critical tool for ensuring food security (Liang et al., 2016). More than 80% of water resources have been exploited for agricultural irrigation (Wang et al., 2011; Egypt in Figures, 2015). Therefore, it is necessary to develop strategies to optimize the efficiency of water use, while maintaining the quantity and quality of the production (Pereira et al., 2012 and Nangare et al., 2016).

Recently, the challenge of irrigated agriculture is how to produce more crops from the limited water supply. One way of tackling this challenge is the adoption of practices that help to improve water management, especially at the field level. The combined practice of deficit irrigation strategy (Topak et al., 2016), mulching and organic matter appears to be very promising in achieving this goal (Abd El-Mageed and Semida 2015a; Abd El-Mageed et al., 2016).

Deficit irrigation (DI) is commonly applied method in arid and semi-arid regions to increase water productivity and water saving (Badal et al., 2013; Ballester et al., 2014 and Shahrokhnia and Sepaskhah, 2016) and defined as the application of water below full crop-water requirements, it is an important tool to achieve the goal of reducing irrigation water use (Fereres and Soriano, 2007). (DI) aims to increase WUE by eliminating irrigation events that have little impact on yield. However, this application can also have other benefits related with

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reducing the energy used during irrigations and decreasing nitrate leaching, maximizing the competitiveness of the agricultural sector (Falagán et al., 2015), reducing production costs and water consumption (Pulupol et al., 1996). Combine practice of deficit irrigation, organic compost and mulching appear to be very promising among the water management practices for increasing WUE, especially at field scale.

Mulching involves the use of organic materials/or inorganic materials to the soil surface to provide one or several ecosystem services such as enriching or protecting the soil, preventing pest establishment or enhancing crop yield (Quintanilla-Tornel et al., 2016). Mulching, is a useful practice with the potential of reducing evaporation, conserving moisture, modifying soil temperature, and improving aeration as well as releasing nutrients in the soil profile (Sharma et al., 2005; Ahmad et al., 2007; Dabney et al., 2001; Liu et al., 2012; Li et al., 2013). Straw mulch can conserve soil water and decrease temperature because it increases residue accumulation and reduces soil disturbance on the soil surface (Baumhardt and Jones, 2002; Zhang et al., 2011 and Yaseen et al., 2014). Zhang et al. (2005) and Abd El-Wahed et al. (2017) found that mulching with straw reduced soil evaporation loss and increased WUE and grain yield). Organic matter inputs through organic amendments, in addition, to improve soil aggregation, supplying nutrients and stimulate microbial diversity and activity (Carpenter-Boggs et al., 2000). Adding organic matter, particularly compost, increases soil water-holding capacity under water deficit (Hirich et al., 2014). Numerous investigations were done on various crops to study the effect of the organic amendment on water-holding capacity of soils and especially under arid and semi-arid conditions and indicating that organic matter input improved field capacity (FC), soil water content (Θ) and increased soil hydraulic conductivity (Ouattara et al., 2006; Wesseling et al., 2009). Organic matter combination in the soil has also a positive effect on plant growth, productivity and yield (Ibrahim et al., 2008, Gopinath and Mina,2011). Supplying organic matter to the soil will improve the soil content nutrients after mineralization of the organic matter and will increase the availability of nutrients for plants; subsequently, the uptake of nutrients will be increased and the growth and productivity of plants will be improved (Hartley et al., 2010). No studies have been conducted on the combined effects of mulch, organic compost and deficit irrigation on sorghum production. Therefore, this study was carried out in order to determine: how organic compost and mulching improve sorghum productivity and growth under deficit irrigation, and the combined effect of deficit irrigation, mulching and organic compost on morphological, physiological responses and plant water status of sorghum

2. Methodology

2.1. Experimental location

two successive field experiments were conducted in summer growing seasons of 2016 and 2017, at the Fayoum University Experimental Station, located in Demo, 5 km East of Fayoum Egypt (30°54055″E 29°17006″N). As represented in Table 1 the tested soil is located under arid climatic conditions, (Ponce et al., 2000). The soil, 0.5–0.80 m deep, is a sandy loam and according to (Soil Survey Staff USDA, 1999) defined as Typic Torripsamments, siliceous, hyperthermic. According to Page et al. (1982) methods the physio- chemical characteristics of the studied soil were conducted Table 2. Treatments were divided into two soil mulching levels (0 and 10 t ha^{-1} of rice straw), three levels of compost (0, 15, 30 t ha^{-1}) and three irrigation levels (I) with three replication for every treatment. I levels was specified as a percentage of the crop evapotranspiration (ET_c) representing one of the following three irrigation treatments: I_{100} = 100%, I_{85} = 85% and I_{70} = 70% of ETc. Irrigation treatments were allocated in the main plots whilst, the mulching was distributed in the sub-plots, finally, the levels of compost were fallen in sub-sub-plots (Table 3).

Table 2
Physico-chemical characteristics of the organic compost.

Characteristics	Value
pH	7.26
EC, dS m^{-1}	3.15
Organic carbon %	46.50
Total N (% DW)	1.30
C/N ratio	35.76
$CaCO_3$, %	1.50
P (g kg^{-1} dry compost)	3.10
Na (g kg^{-1} dry compost)	0.30
Mg (g kg^{-1} dry compost)	0.38
Ca (g kg^{-1} dry compost)	0.40
K (g kg^{-1} dry compost)	4.20
Total fibers (% DW)	32.4
WHC (g water/g dry compost)	6.24
Moisture content (%)	39.75

DM is the dry mass, WHC is the water-holding capacity.

2.2. Irrigation water application

The sorghum plants were irrigated at ten days intervals by different amounts of irrigation water. The crop water requirements (ETc) were estimated using the crop coefficient according to Allen et al. (1998) equation:

$$ETc = Epan \times Kpan \times Kc$$

Where: ETc = crop water requirements (mm d^{-1}), *Epan* = evaporation from the Class A pan (mm d^{-1}), K*pan* = the pan evaporation coefficient and Kc = crop coefficient. The plots involved irrigation treatments were isolated with 200 cm fallow land to avoid the lateral movement of water from irrigation level to another. Subplots within each irrigation treatment were isolated by a distance of 0.5 m fallow land. The area of the experimental plot was 12 m^2 (3 m × 4 m) and the number of plots

Table 1
Weather data at Fayoum area, Egypt during SI (2016) and SII (2017) seasons.

Month	SI (2016)					SII (2017)				
	Main temperatures (°C)		RH_{avg} %	U_2 ms^{-1}	E_p mmd^{-1}	Main temperatures (°C)		RH_{avg} %	U_2 ms^{-1}	E_p mmd^{-1}
	day	night				day	night			
May	37.36	21.43	41.68	1.90	6.49	36.5	19.5	30	1.93	6.90
June	39.48	23.43	42.73	1.50	8.30	36.4	19.3	30	1.60	6.90
July	40.92	25.07	41.22	2.00	7.50	40.3	25.9	36	2.10	7.60
August	38.10	25.20	49.50	1.60	6.80	40.4	26.0	36	1.80	6.90
September	36.6	23.60	43.70	2.10	5.80	38.3	23.8	36.0	2.12	5.5

RH_{avg} is average relative humidity, U_2 is average wind speed, and E_P is average of measured pan evaporation class A.

Table 3
Physical and chemical properties of the studied soils.

Layer (cm)	Particle size distribution				Bulk density g cm^{-3}	K_{sat} cm h^{-1}	Soil moisture content at			pH	ECe dS m^{-1}	$CaCO_3$, %	OM, %
	Sand %	Silt %	Clay %	Texture class			F.C %	W.P %	A. w %				
0-20	66.07	15.08	18.85	S.L.	1.40	2.86	24.00	10.02	13.98	7.65	3.18	7.90	0.97
20-40	72.62	11.09	16.29	S.L.	1.47	2.99	21.72	9.15	12.57	7.62	3.07	6.5	0.74
40-60	75.61	9.15	15.24	S.L.	1.56	3.26	19.71	8.05	11.66	7.53	3.08	5.22	0.31

LS = Sandy loam, F.C = Field capacity, W.P = Wilting point, A.W = Available water and K_{sat} = Hydraulic conductivity and OM = Organic matter.

was 54 for each year. The amounts of irrigation water applied to each plot during the irrigation regime were determined by using the following equation

$$IWA = \frac{A \times ETc \times Li}{Ea \times 1000}$$

Where IWA is the irrigation water application (m^3), A is the area (m^2), ET_c is crop water requirements (mm d^{-1}), Li is the irrigation intervals (day), and Ea is the application efficiency (%). The amount of irrigation water application (IWA) was controlled through a plastic pipe (spiles) of 50 mm diameter. For each plot, one spile per plot was used to convey water under surface irrigation system. The amount of water delivered through a plastic pipe was calculated according to Israelsen and Hansen (1962).

$$Q = CA\sqrt{2gh} \times 10^{-3}$$

Where: Q is the discharge of irrigation water (l s^{-1}), C is the coefficient of discharge, A is cross section area of irrigation pipe (cm^2), g is gravity acceleration (cm sec^{-2}) and h is the average of the effective head of water (cm).

2.3. Plant management and physiological measurements

2.3.1. Planting and fertilization

Sorghum (var. Hours hybrid) was sown on 1st June 2016 and 25th May 2017 in hills spaced by 20 cm within rows, 60 cm apart. Phosphorus in the form of calcium superphosphate (15.5% P_2O_5), at the rate of 375 kg ha^{-1} was applied to the soil during seed bed preparation. Nitrogen in the form of ammonium nitrate (33.5% N) at the rate of 75 kg ha^{-1} was applied in two equal doses during the growing period (20 and 40 days after sowing).

2.4. Measurements

Soil water content (SWC) was monitored by digital WET sensors (Moisture Meter type HH2, Cambridge, CB5 0 EJ, UK). Canopy temperature (Tc) was measured with a hand-held infrared thermometer (Fluk 574, Everett WA, USA) at an emissivity of 0.98 and a spectral response range of 8–14 μm. By the end of every season, five individual plants were randomly sampled from each plot and plant growth characteristics (e.i. plant height, leaves No., stem diameter, shoot dry weight and leaf area) were measured. Leaf area per plant was determined using digital planometer (Planix 7).

Chlorophyll 'a', chlorophyll 'b' and carotenoid content were extracted and determined (in mg g^{-1} FW) according to the procedure given by Arnon (1949). Fresh leaf samples (0.2 g) were homogenized in 50 ml 80% (v/v) acetone and then centrifuged at 10,000 × g for 10 min. The absorbance of the acetone extract was measured at 663, 645, and 470 nm using a UV-160 A UV–vis recording spectrometer (Shimadzu, Kyoto, Japan). Relative water content (RWC%) was estimated according to (Hayat et al., 2007) and calculated using the following formula:

$$RWC(\%) = \left[\frac{(FM - DM)}{(TM - DM)}\right] \times 100$$

Where: FM is the fresh mass, TM: is the turgid mass and DM is the dry mass

Membrane stability index (MSI%) was measured using the method of Premchandra et al. (1990) and calculated by the following equation.

Where: MSI% is the membrane stability index, C_1: is the electrical conductivity of the solution at 40 °C and C_2: is the electrical conductivity of the solution at100 °C. Shoots fresh of plants were weighed and then placed in an oven at 70 ± 2 °C till a constant weight to measure their dry weights.

2.5. Sorghum yields (seeds and forage) and harvest index (HI)

At harvesting, ten guarded plants were taken at random from each plot and used to measure averages of the forage yield, numbers of leaves, plant height, and seeds, as well as harvest index (HI). Seeds of all plants per plot were used to determine seed yield per hectare and 100 seed were weighted. HI was determined as a ratio of seed yield to total biomass production on a dry mass basis.

2.6. Water use efficiencies

Water use efficiencie**s** (WUE) were calculated as (i) the ratio between above ground biomass and crop evapotranspiration, i.e. forage WUE (F- WUE) and (ii) the ratio between seed yield and crop evapotranspiration, i.e. seed WUE (S- WUE).

2.7. Statistical analysis

The collected data during the two years of experimental work were analyzed according to a split-split plot arrangement in a randomized complete block design. Statistical analysis was performed through the GLM procedure of Gen STAT. The least significant difference (LSD) at 0.05 and 0.01 probability level was used as mean separation test.

3. Results and discussion

3.1. Metrological conditions and volume of irrigation water applied

The main weather parameters, including, air temperature, relative humidity, "class A" pan evaporation and wind speed, were collected from a standard agro-meteorological station located about 10 km from the experimental field. The weather regime during two experimental seasons was shown in Table 1. Maximum daily temperature as average for two seasons was ≈38.45 °C, minimum daily temperature (night) was ≈23.32.45 °C while, air relative humidity was usually ≈38.68%. The total amount of irrigation volumes applied as average for two years were 671.15, 570.48 and 496.81 mm for well irrigated (control 100% of ETc), moderate stress (85% of ETc), and severe water stress (70% of ETc), respectively.

Table 4
Effect of organic compost (OC) application rate on some physical and chemical properties after harvest as average for two seasons.

organic compost (t h^{-1})	ECe (dS m^{-1})	Soil pH	O.M %	Bulk density g cm^{-3}	Total porosity %	WHP* %	U.P %	F.C %	A. W %
OC_0	3.2^A	7.65^A	0.98^C	1.45^A	38.21^B	14.69^C	19.81^C	24.32^C	13.98^C
OC_{15}	3.1^B	7.54^B	1.16^B	1.42^B	39.31^A	16.46^B	21.5^B	27.28^B	16.35^A
OC_{30}	3.1^B	7.53^C	1.24^A	1.39^C	40.66^A	17.67^A	22.71^A	28.67^A	17.62^A

W.H.P = Water holding pores % and U.P = Useful pores %.

Table 5
Effect of mulching and organic compost application on growth characteristics of sorghum plants grown under different irrigation levels (I) in 2016 (SI) and 2017 (SII) seasons.

Source of variation	Plant height (cm)		Number of leaves/plant		Leaf area/ plant (dm^2)		Stem diameter (cm)		Shoot dry weight/ plant (g)	
	SI	SII	SI	SII	SI	SII	SI	SII	SI	SII
Irrigation(I)	**	**	**	**	**	**	**	**	**	**
I_{100}	165a	134.8a	12a	11a	481.7a	481.2a	2.2a	1.79a	296.6a	239.8a
I_{85}	156b	132.9b	11b	10b	449.8b	449.2b	2.0b	1.71b	290.8b	209.4b
I_{70}	138c	128.9c	10c	11a	382.1c	381.5c	1.7c	1.69b	260.0c	205.3b
Mulch(M)	**	**	Ns	Ns	**	**	**	**	**	**
M^-	150b	131.5b	11	10	417.5b	416.9b	1.9b	1.66b	279.1b	214.6b
M^+	157a	132.8a	11	11	458.2a	457.7a	2.0a	1.88a	285.9a	221.7a
Organic compost (OC)	**	**	**	*	*	*	**	**	**	**
OC_0	149c	127.2c	10b	10b	426.9b	426.3b	1.7c	1.58c	268.2c	190.9c
OC_{15}	154b	131.1b	11a	11a	444.0a	443.5a	2.0b	1.71b	285.6b	219.9b
OC_{30}	157a	138.2a	11a	11a	442.6a	442.1a	2.1a	1.90a	293.6a	243.6a
I × M	**	Ns	**	*	Ns	Ns	Ns	**	Ns	**
I × OC	Ns	*	Ns	Ns	Ns	Ns	**	**	*	**
M × OC	Ns	Ns	Ns	Ns	Ns	Ns	Ns	**	Ns	Ns
I × OC × M	Ns	Ns	Ns	Ns	Ns	Ns	Ns	NS	Ns	*

** and * indicate, respectively, differences at P ≤ 0.05 and P ≤ 0.01 probability level, ns indicates not significant difference. Means followed by the same letter in each column are not significantly different according to the LSD test (P < 0.05).

Table 6
Effect of mulching and organic compost application on the concentrations of leaf photosynthetic pigments and plant water status of sorghum plants grown under different irrigation levels (I) in 2016 (SI) and 2017 (SII) seasons.

Source of variation	Chlorophyll 'a' (mg g^{-1} FW)		Chlorophyll 'b' (mg g^{-1} FW)		Carotenoids (mg g^{-1} FW)		RWC%		MSI%	
	SI	SII	SI	SII	SI	SII	SI	SII	SI	SII
Irrigation (I)	**	**	**	**	**	**	**	**	**	**
I_{100}	0.31a	0.28a	0.02a	0.017a	0.08a	0.07a	83.2a	81.8a	23.2a	23.0a
I_{85}	0.26b	0.26b	0.01b	0.015b	0.07b	0.06b	76.2b	77.7b	20.9b	19.6b
I_{70}	0.26b	0.23c	0.02a	0.014c	0.06c	0.05c	70.9c	72.8c	18.1c	18.0c
Mulch (M)	**	Ns	**	**	**	**	*	**	*	**
M^-	0.27b	0.26	0.01b	0.015b	0.06b	0.06b	77.5b	76.1b	20.1b	19.5b
M^+	0.29a	0.26	0.02a	0.016a	0.07a	0.07a	79.9a	78.8a	21.4a	21.0a
Organic compost (OC)	**	**	**	**	**	**	**	**	**	**
OC_0	0.25c	0.23c	0.01c	0.011c	0.06c	0.05c	66.0c	68.0c	16.5c	16.3c
OC_{15}	0.27b	0.25b	0.02b	0.015b	0.07b	0.07b	77.8b	78.4b	20.8b	19.6b
OC_{30}	0.31a	0.30a	0.03a	0.020a	0.08a	0.08a	86.4a	86.0a	25.0a	24.8a
I × M	**	NS	**	NS	**	**	**	**	**	**
I × OC	NS	NS	**	NS	**	**	**	**	Ns	NS
M × OC	**	NS	NS	NS	NS	NS	NS	Ns	Ns	NS
I × OC × M	**	NS	**	NS	**	**	**	**	*	**

** and * indicate, respectively, differences at P ≤ 0.05 and P ≤ 0.01 probability level, ns indicates not significant difference. Means followed by the same letter in each column are not significantly different according to the LSD test (P < 0.05).

3.2. Effect of organic compost (OC) application rates on some physical and chemical properties

Table 4 show the effect of C application on soil physico-chemical of the studied soil. The obtained results reflect that soil electrical conductivity (ECe) and soil pH values decrease significantly (P ≤ 0.05) with increasing OC level. This attributed could be to the accumulation of active organic acids and the cation exchange capacity (CEC) of OC which led to a reduction in soil pH values. In addition, the reduced pH of the OC (7.26; Table 2) contributed to decrease the soil pH. The reduction of ECe values probably due to the occurrence of the charged sites (i.e., COO^-) accounts for the ability of organic compost (OC) to chelate and retain cation in non-active forms. Addition of OC_{15} (15 t ha^{-1}) or OC_{30} (30 t ha^{-1}) to the soil significantly increased soil organic matter content compared with control treatment (OC_0) Also, data in Table 4, show a gradual decrease in soil bulk values with increasing OC

Table 7
Effect of mulching and organic compost application on harvest index (HI), Diurnal variation in (Tc-Ta) of sorghum plants grown under different irrigation levels (I) in 2016 (SI) and 2017 (SII) seasons.

Treatments	HI		Tc-Ta			
			O'clock			
			14:00		15:00	
	SI	SII	SI	SII	SI	SII
Irrigation(I)	**	**	**	**	**	**
I_{100}	0.15b	0.20a	−13.74a	−10.15a	−8.43a	−8.61a
I_{85}	0.16a	0.19b	−8.62b	−5.67c	−8.40a	−5.61b
I_{70}	0.14c	0.18c	−8.15b	−6.50b	−7.02b	−4.98c
Mulch(M)	NS	**	**	**	**	**
M^-	0.15	0.18b	−9.78b	−6.97b	−7.32b	−5.26b
M^+	0.15	0.19a	−10.56a	−7.93a	−8.57a	−7.54a
Organic compost (OC)	**	**	**	**	**	**
OC_0	0.15b	0.18b	−9.10c	−6.81b	−6.60b	−5.30c
OC_{15}	0.15b	0.18b	−10.89a	−7.66a	−8.63a	−6.69b
OC_{30}	0.16a	0.20a	−10.51b	−7.88a	−8.61a	−7.21a
I × M	**	**	NS	**	**	**
I × OC	**	**	**	**	NS	*
M × OC	NS	**	NS	**	NS	NS
I × OC × M	**	**	*	**	**	NS

** and * indicate, respectively, differences at $P \leq 0.05$ and $P \leq 0.01$ probability level, ns indicates not significant difference. Means followed by the same letter in each column are not significantly different according to the LSD test ($P < 0.05$).

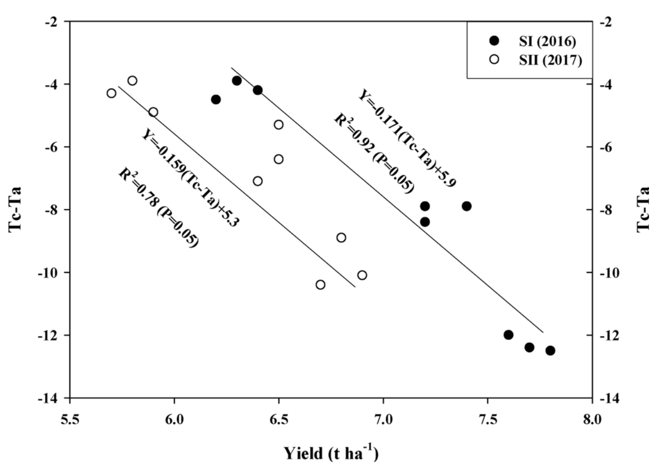

Fig. 1. Relationship between sorghum seed yield and canopy–air–temperature differential (Tc − Ta) at flowering stage in 2016 (SI) and 2017 (SII) seasons.

level, where the highest level (30 t ha^{-1}) gave the lowest soil bulk density value (1.39 g cm^{-3}). This positive effect could be refer to the pronounced content of organic colloidal particles, which plays an great role in modifying distribution pattern of pore spaces in the soil. These findings are in agreement with those obtained by Semida et al. (2014) and Abd El-Mageed and Semida (2015b) who mentioned that bulk density was closely linked to solid phase properties and pore spaces. Applied of OC possesses a positive effect for soil bulk density (i,e., reduced its value), therefore it leads to increase the total porosity of the soil. In addition, integrative application of OC_{15} or/OC_{30} further increased soil water properties by 12 and 20.3% for water holding pores (WHP), 8.5 and 14.6% for useful pores, 2.9 and 6.4% for total porosity, 12.2 and 17.9% for field capacity, 17 and 26% for available water as compared with control (OC_0). The above-mentioned case is more attributed to an increase in soil moisture content at field capacity Table 4. However the addition of OC to soil encouraged the creation of medium and micro pores (i.e., water holding capacity and useful pores) between simple packing sand particles, and in turn, increasing capillary potential. Such organic substances of compost have high ability to retain a pronounced content of water (Askar et al., 1994). These results are emphasized by Cheng et al. (1998) and Rady et al. (2016b) who reported that, active organic acids decreased the loss of soil moisture, and in turn enhanced the water retention.

3.3. Leaf photosynthetic pigments

Table 6 report decreases content of chlorophyll 'a', chlorophyll 'b' and total carotenoids in sorghum leaves as a result of water stress. These photosynthetic pigment components were significantly reduced gradually with the gradual increase in DI for both seasons. However, application of organic compost and mulching have been shown to increase leaf photosynthetic pigment concentration. Except for some fluctuations in both seasons, $M^+ + OC_{15}$ or $OC_{30} + I_{100\%}$, $M^+ + OC_{15}$ or $OC_{30} + I_{85\%}$ or $M^+ + OC_{15}$ or $OC_{30} + I_{70\%}$ treatment significantly increased the concentration of leaf photosynthetic pigments compared to $I_{100\%}$, $I_{80\%}$ or $I_{60\%}$ treatment, respectively. The $M^+ + OC_{15}$ or $OC_{30} + I_{70\%}$ treatment generated sorghum plants with the highest values of the leaf photosynthetic pigments at the concentration of which plants can overcome drought stress. Inhibition of photosynthesis in sorghum plants caused by water stress in our study could be due to the decreased content of chlorophylls and carotenoids (Table 6). The reduction in chlorophyll content due to osmotic stress has been ascribed to the strong damage and loss of chloroplast membranes (Kaiser et al., 1981). The decrease in photosynthetic performance under water stress has also been observed by Ben Ahmed et al. (2009) and Habibi (2012). Compost could have favored leaf growth and a new sink developed which would reduce soluble carbohydrates (Isopp et al., 2000; Rady et al., 2016a).

3.3. Plant growth characteristics

Plant height, cm, number of leaves $plant^{-1}$, leaf area $plant^{-1}$ (dm^2) stem diameter, (cm) and shoot dry weight $plant^{-1}$ (g) were statistically analyzed as shown in Table 5. All this traits were highly significant affected by irrigation quantity, soil mulching and organic compost. Except shoot dry weight in second season, all growth attributes were not significantly affected by interaction between organic compost and both irrigation and mulching treatments. The highest values of all traits, had been recorded when sorghum plants were subjected to full irrigation ($I_{100\%}$) and received 30 t ha^{-1} of organic compost (OC_{30}) and mulched with 10 t ha^{-1} of rice straw as average for two seasons. However, the lowest values were obtained under water-deficit conditions (I_{70}) combined with 0 t ha^{-1} organic compost (OC_0) and with unmulched (0 t ha^{-1}) treatment. Organic compost (OC) applications had clear effect on plant growth and biomass production. The improved growth attributes of sorghum plants produced as a result of increased application rate of OC could be attributed to the increase decomposition of the OC and mineralization of nutrients (Ojo et al., 2014). In addition, the suggestion that OC has an effective role on metabolic of soil biota as soon as the dynamic of uptake of soil nutrients and physical soil properties, reflecting in an enhancement of plant growth and productivity (Semida et al., 2014, Ouni et al.,2014 and Rady et al., 2016b)

Plant height, stem diameter, leaf area $plant^{-1}$ and shoot dry weight $plant^{-1}$ (g) were significantly ($P < 0.05$) decreased under stressed treatment. However, organic compost (OC), mulching influence on yield were more important under deficit irrigation conditions. Results indicated that dry matter of plant was negatively affected by deficit irrigation. Moreover, dry weight of the whole plant as well as that of individual plants was higher in the control (100% of ETc) than I85% or I70% of ETc. This results also in agreement also with those obtained by Wolka and Melaku (2015) and Mukhlis et al. (2017)

Table 8
Effect of mulching and organic compost application on forage yield, seed yield of sorghum plants, F-WUE and S-WUE under different irrigation levels (I) in 2016 (SI) and 2017 (SII) seasons.

Source of variation	Weight of 100 seeds (g)		Forage yield (t ha^{-1})		Seed yield (t ha^{-1})		F-WUE (kg m^{-3})		S-WUE (kg m^{-3})	
	SI	SII	SI	SII	SI	SII	SI	SII	SI	SII
Irrigation (I)	**	**	**	**	**	**	**	**	**	**
I_{100}	2.5a	2.6a	40.94a	41.1a	7.6a	6.7a	6.4c	6.0c	1.1c	1.0c
I_{85}	2.1b	2.5b	40.14a	40.6a	7.5a	6.6a	7.3b	7.0b	1.3b	1.1b
I_{70}	2.0c	2.2c	35.82b	36.7b	6.3b	6.0b	7.9a	8.1a	1.4a	1.3a
Mulch (M)	**	**	**	*	**	**	**	**	**	**
M^-	2.1b	2.3b	35.48b	35.9b	6.5b	6.4b	6.6b	6.92b	1.2b	1.1b
M^+	2.3a	2.5a	39.45a	40.7a	7.2a	6.9a	7.3a	7.03a	1.3a	1.2a
Organic compost (OC)	**	**	**	**	**	**	**	**	**	**
OC_0	2.1c	2.2c	37.01c	37.3c	6.6c	5.8c	6.9c	6.4c	1.2c	1.0c
OC_{15}	2.2b	2.4b	39.37b	41.4b	7.0b	6.1b	7.3b	7.1b	1.3b	1.1b
OC_{30}	2.3a	2.7a	40.52a	42.3a	7.9a	7.7a	7.5a	7.4a	1.4a	1.3a
I × M	**	**	NS	*	**	**	NS	**	**	**
I × OC	**	**	**	**	**	**	*	**	*	*
M × OC	**	**	NS	NS	**	**	NS	NS	**	**
I × OC × M	**	**	NS	NS	**	**	NS	NS	**	**

** and * indicate, respectively, differences at P ≤ 0.05 and P ≤ 0.01 probability level, ns indicates not significant difference. Means followed by the same letter in each column are not significantly different according to the LSD test (P < 0.05).

Table 9
Effect of irrigation treatments, mulching and organic compost applications on water saving (WS), sorghum seed yield (SY), forage yield (FY), seed yield reduction (SYR) and forage yield reduction (FYR) as average for both seasons.

Treatments	IWA	WS %	Unmulched (M^-) SY (t ha^{-1})	SYR%	FY (t ha^{-1})	FYR %	Mulched (M^+) SY (t ha^{-1})	SYR %	FY (t ha^{-1})	FYR%
OC_0										
I_{100}	6711.5	0	6.28	0	38.77	0	6.37	0	39.16	0
I_{85}	5704.8	15	6.08	3.2	37.32	3.7	6.37	0	39.0	0.4
I_{70}	4698.1	30	5.69	9.7	35.89	7.7	6.10	4.2	36.29	7.5
OC_{15}										
I_{100}	6711.5	0	6.76	0	42.25	0	6.83	0	42.57	0
I_{85}	5704.8	15	6.64	1.8	40.80	3.4	6.72	1.6	42.46	0.3
I_{70}	4698.1	30	6.14	9.3	40.86	3.4	6.26	8.5	39.17	8.0
OC_{30}										
I_{100}	6711.5	0	8.25	0	43.69	0	8.42	0	43.9	0
I_{85}	5704.8	15	8.04	2.6	43.12	1.3	8.19	2.7	43.89	0.2
I_{70}	4698.1	30	6.67	19.7	39.81	9.0	7.21	14.8	39.95	9.0

3.5. Canopy temperature

Canopy temperature estimations are an important process and it is conceder a good indicator for plant water status monitoring when plants are undergoing drought stress. The conductance of water through stomata on leaves decreases when water supply becomes limited to the plant roots and canopy temperature will be increased. In this concern, Olivo et al. (2009) reported that, canopy temperature, relative to ambient temperature, changes as a result of stomatal conductance control of plant transpiration. Moreover, transpiration decreases and plant temperature may exceed air temperature if plant water stress increases, On the other hand; well water plants will have canopy temperatures (Tc) less than ambient air temperature (Ta), particularly when vapour pressure deficit (VPD) is not greater than 4 kPa. Canopy temperature might increase 6–8∘C (Tc-Ta) Table 7 under ($I_{70\%}$), and at flowering stage of sorghum, compared to the well-irrigated plants ($I_{100\%}$). The canopy temperature of plants was significantly and negatively correlated with seed yield (linear with $R^2 = 0.92$ in SI (2016) and 0.78 in SII (2017) seasons Fig. 1) similar to what has been reported for other crops; Zhang et al., 2007, (rice), Reynolds et al., 2001 (wheat) and Abd El-Mageed et al., 2016 for (squash). The results in Table 5, reveal that lower irrigation quantity or sever DI ($I_{70\%}$), would cause larger canopy-air ambient temperature (Tc-Ta) difference at the flowering stage and lead to lower seed yield. Therefore, the canopy temperature of sorghum is closely correlated to the water quantity and could be used to monitor crop water status, and would be regarded as one of the determinants for reasonable irrigation and drought analysis. Data in Table 7 show that, the canopy temperature was lower than air temperature, and the irrigation treatment significantly affected on canopy temperature for both growing seasons Turner et al. (1986) and Abd El-Mgeed and Semida (2015a). Results in Table 7 show that canopy–air–temperature differential (Tc − Ta) at flowering was significantly affected by mulch treatments. Under (M^+) canopy–air–temperature (Tc-Ta) was significantly decreased compared to with (M^-) in SI (2016) and SII (2017) years Table 7. These attributes may be due to an increases in soil moisture content at field capacity and then available water content increased under mulching (Debashis et al., 2008; Abd El-Mgeed et al., 2016).

3.6. Relative water content (RWC) and membrane stability index (MSI)

Responses of RWC and MSI of sorghum plants for irrigation, mulching and organic compost are presented in Table 6. Statistical analysis carried out on RWC and MSI revealed a significant difference (P ≤ 0.05 or/and P ≤ 0.01) between irrigation, mulching and organic compost treatments. RWC and MSI values were decreased with

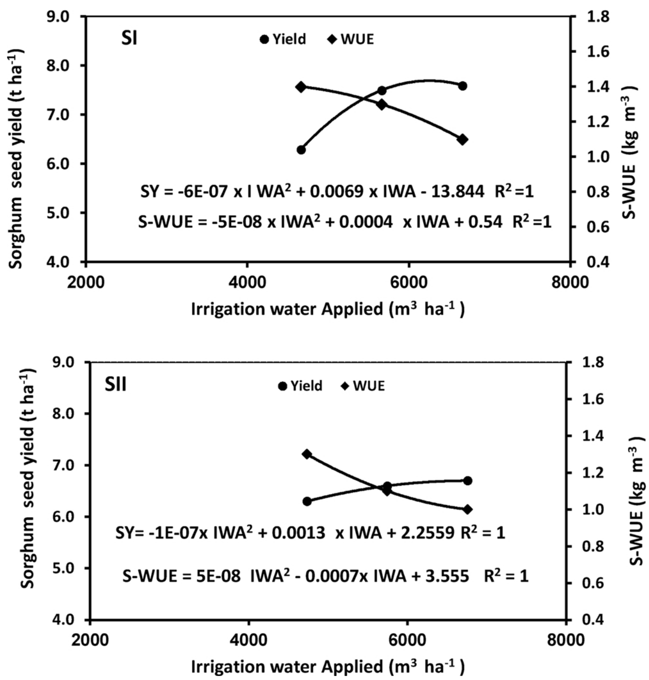

Fig. 2. Regression analysis between sorghum seed yield, irrigation water applied and S-WUE in 2016 (SI) and 2017 (SII) seasons.

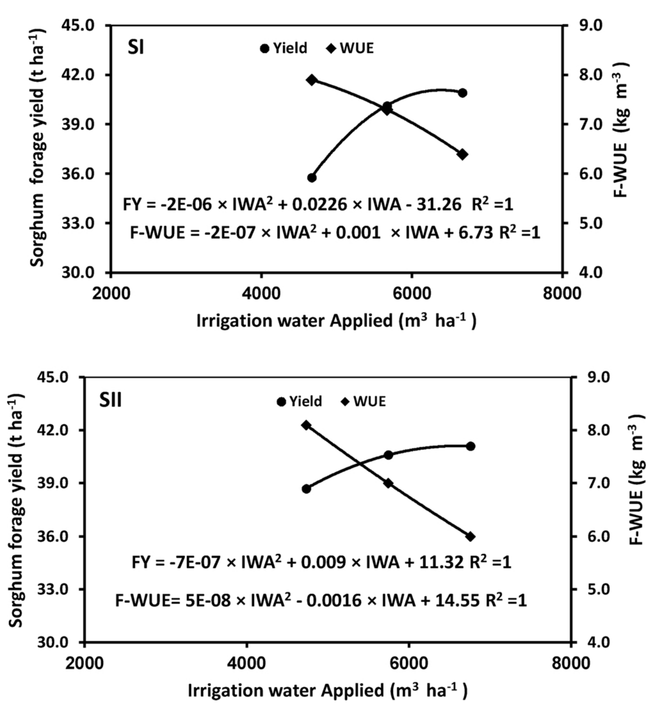

Fig. 3. Regression analysis between sorghum forage yield, irrigation water applied and F-WUE in 2016 (SI) and 2017 (SII) seasons.

increasing of water stress. The greatest values of RWC and MSI (82.5 and 23.1%) were obtained under 100% of ETc compared to (71.85 and 18.1%) 70% of ETc as the average for both seasons. As compared to the control treatment (OC_0, 0 t ha^{-1}), plants treated by either 15 or 30 t OC h^{-1}, revealed a significant increase ($P \leq 0.05$ or $P \leq 0.01$) in dehydration tolerance in terms of increased RWC% and MSI (Table 6). The same trends were observed in both seasons. The best results of these parameters were obtained under application of OC30 + M^+ + I100 of ETC. According to Sinclair and Ludlow (1986), RWC is considered as a measure of plant water status and reflecting the metabolic activity in plant tissues. Application of higher rates of OC improved RWC and MSI (Rady et al., 2016a). A relationship was observed between RWC and plant biomass (dry weight) under the interactive effect of water levels, OC and M, indicating that the water status in sorghum leaves is basically dependent on the respective shoot biomass (Table 5). According to Kabir et al. (2004) and Rady et al. (2016b) plants having greater biomass can maintain higher water content in leaf, leading to more tolerance to drought.

3.7. Harvest index, forage and seed yields

Exhibited data in Tables 7 and 8 illustrate that harvest index HI, 100 seed weight (g) forage and seed yields (t ha^{-1}) were significantly affected by the irrigation quantity, mulching and organic compost applications. Table 7 show that HI was significantly affected ($P \leq 0.05$) by the irrigation level and the greatest values were recorded under full irrigated treatment and they were 0.15 and 0.20 for SI and SII, respectively. On the other hand, the lowest values were recorded under $I_{70\%}$ (0.14 and 0.18 for SI and SII). The effects of mulching on HI was not significantly affected in first year (SI, 2016) while, it was significant in the second year (SII, 2017). Concerning, the effects of OC on HI, results in Table 7 show that the values of HI were significantly affected ($P \leq 0.05$) by OC rates and the heights were obtained under OC_{30} (0.16 for SI and 0.20 for SII). Moreover, the highest (HI) was recorded when sorghum plants were subjected to full irrigation (I_{100}) and received 30 t ha^{-1} of OC and mulched with 10 t ha^{-1} for both seasons. Data in Table 7 indicate that HI value was significantly affected by the interactions between OC rates, M, and irrigation level in two seasons. The obtained results are found to be in agreement also with those obtained by Ofosu-Anim and Leitch (2009) and Abdel-Mageed et al., (2016).

Results presented in Table 8 show that the values of 100 seed weight, seed yield (SY) and forage yields (FY) were significantly affected by irrigation, mulching, and organic compost application. The highest SY and FY (7.1 and 40.1 t ha^{-1}) values were recorded under M^+ (10 t ha^{-1}) compared to (6.45 and 35.69 t ha^{-1}) unmulched treatment (M-, 0 t ha^{-1}) as the average for both seasons. This result is in line with that of Abd El-Wahed and Ali (2013) and Abd El-Mageed, et al. (2016). They reported that the average of yields of Maize and squash for mulched treatment were increased than unmulched treatment. Data introduced in Tables 8 and 9 show that SY and FY values were significantly affected by the irrigation quantity. The highest SY and FY (7.15 and 41.02 t ha^{-1}) values were obtained under 100 of ETc compared to (6.3 and 36.26 t ha^{-1}) under 70 of ETc as the average for both seasons 2016 and 2017, respectively. These results are in agreement with those of (Amer, 2011).

Regarding the effect of organic compost (OC) on SY and FY, values obtained in Table 8 show that SY and FY were significantly affected by the organic compost level application. The average SY and FY values of OC_{30} (7.8 and 41.41 t ha^{-1}) were increased by 25.1 and 11.45% than those of OC_0 (6.2 and 37.16 t ha^{-1}), for SY and FY, respectively. A similar trend was reported by (Abd El-Wahed and Ali, 2013) they added that this result is logic since the same treatment gained the highest seed yield which compensated the I_{100}. The relationship between IWA and SY was curvilinear (polynomial of 2nd order) Fig. 2, and it could be expressed as follows:

$$SY = -6E\text{-}07 \times I\,WA^2 + 0.0069 \times IWA - 13.84 \quad R^2 = 1 \text{ for SI (2016)}$$

$$SY = -1E\text{-}07 \times IWA^2 + 0.0013 \times IWA + 2.26 \quad R^2 = 1 \text{ for SII (2017)}$$

Where SY is the seed yield (t ha^{-1}), and IWA is irrigation water applied (m^3 ha^{-1}). Also, the relationship between IWA and FY (Fig. 3) could be expressed as follows:

$$FY = -2E\text{-}06 \times IWA^2 + 0.0226 \times IWA - 31.26 \quad R^2 = 1 \text{ for SI (2016)}$$

$$FY = -7E\text{-}07 \times IWA^2 + 0.009 \times IWA + 11.32 \quad R^2 = 1 \text{ for SI (2017)}$$

Where FY is the forage yield (t ha^{-1}), and IWA is irrigation water applied (m^3 ha^{-1}). Data in Table 8 indicated that FY was not significantly affected by the interactions between compost rates, mulching and irrigation level in two seasons. In contrast, SY was significantly affected by the interactions between the tested treatments in both seasons.

3.8. Seed and forage water use efficiencies (S-WUE and F-WUE)

Results in Table 8 demonstrate that S-WUE and F-WUE values were significantly affected by mulching, irrigation and organic compost treatments. As an average for two seasons, the highest S-WUE and F-WUE (1.25 and 7.17 kg m^{-3}) values were recorded under M^+ (10 t ha^{-1}) compared to (1.15 and 7.01 kg m^{-3}) unmulched treatment (M-, 0 t ha^{-1}). This result due to the sorghum seed and forage yields obtained under M^+ treatment (7.1 and 40.1 t ha^{-1}) were higher than the corresponding sorghum yields (seed and forage) obtained under M-treatment (6.45 and 35.69 t ha^{-1}) by 10.1 and 12.4%, (under the same amount of irrigation water applied) as average for two seasons, (Table 8). The result is in line with that of Kar and Kumar (2007); Abd El-Wahed and Ali (2013) and Abd El-Mageed, et al. (2016). They reported that the average of WUE values of maize and squash for mulched treatment were increased than unmulched treatment. Table 8 show that S-WUE and F-WUE values were significantly affected by the irrigation quantity. The highest S-WUE and F-WUE (1.35 and 8.0 m^{-3}) values were obtained under $I_{70\%}$ compared to (1.05 and 6.2 kg m^{-3}) under $I_{100\%}$, in both seasons, respectively. These results are in agreement with those of (Abd El-Mageed, et al., 2016). Regarding the effect of organic compost (OC) on S-WUE and F-WUE Table 8 show that S-WUE and F-WUE values were significantly affected by the organic compost application. The average S-WUE and F-WUE values of OC_{30} (7.8 and 41.41 t ha^{-1}) were increased by 25.1 and 11.45% than those of OC_0 (6.2 and 37.16 t ha^{-1}), for S-WUE and F-WUE, respectively. A similar trend was reported by (Abd El-Wahed and Ali, 2013) they added that this result is logic since the same treatment gained the highest grain yield which compensated the I_{100}. As presented in Fig. 3, the relationship between IWA and S-WUE was curvilinear (polynomial of 2nd order) and it could be expressed as follows:

$$S\text{-}WUE = 5E\text{-}08\ IWA^2 - 0.0007x\ IWA + 3.555 \quad R^2 = 1 \text{ for SI (2016)}$$

$$S\text{-}WUE = -5E\text{-}08\ x\ IWA^2 + 0.0004\ x\ IWA + 0.54 \quad R^2 = 1 \text{ for SII (2017)}$$

Where S-WUE is the seed water use efficiency (kg m^{-3}), and IWA is irrigation water applied (m^3 ha^{-1}). Also, the relationship between IWA and F-WUE could be expressed as follows:

$$F\text{-}WUE = -2E\text{-}07 \times IWA^2 + 0.001 \times IWA + 6.73 \quad R^2 = 1 \text{ for SI (2016)}$$

$$F\text{-}WUE = 5E\text{-}08 \times IWA^2 - 0.0016 \times IWA + 14.55 \quad R^2 = 1 \text{ for SI (2017)}$$

Where F-WUE is the forage water use efficiency (kg m^{-3}), and IWA is irrigation water applied (m^3 ha^{-1}). Data in Table 8 indicated that F-WUE was not significantly affected by the interactions between compost rates, mulching, and irrigation level in two seasons. On the other hand, S-WUE was significantly affected by the interactions between the tested treatments in both seasons.

3.9. Conclusion

Exposure of sorghum plants to drought stress resulted in decreases in plant growth attributes, MSI%, RWC, leaf photosynthetic pigments, harvest index seed and forage yields and increase canopy temperature. Overall, the present study reflected that OC and M application could overcome the adverse effects of water stress by increasing, plant water status, chlorophyll "a" and chlorophyll "b" and enhancing plant growth and water use efficiencies. In this instance, OC appeared to be a viable substitute to decrease soil salinity (ECe), soil pH, and soil bulk density and increase field capacity, water holding pores, useful pores, total porosity, and soil organic matter content. Consequently, OC and M application enhanced plant growth, productivity, water use efficiencies (S-WUE and F-WUE). Results indicated that OC of 15 t ha^{-1} and 30 t ha^{-1} significantly ($p \leq 0.05$) increased seed yield by 5.6 and 25.8%, Also, the forage yield increased by 8.7 and 11.45% with respect to control (OC_0 0 t/ha^{-1}). Moreover, soil mulching (10 t ha^{-1}) increased SY and FY by 9.3 and 12.3 compared to unmulched treatment (M-, 0 t ha^{-1}). Depending on the results of the present work it could be stated that the treatment ($I_{100} \times OC_{30} \times M_{10}$) is the most suitable for producing high sorghum yields under the conditions of the study area. Under limited irrigation water, application of ($I_{85} \times OC_{30} \times M_{10}$) treatment was found to be favorable to save 15% of the applied irrigation water, providing the same sorghum crop yields. Under newly reclaimed soil, the combined practice of deficit irrigation and organic compost, mulching with rice straw appears to be very promising in maximizing crop water productivity.

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