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Optimizing Grain Sorghum (*Sorghum bicolor L.*) Productivity Under Full Irrigation and Stress Using Humic Acid in Arid Regions

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Abstract

A field experiment was carried-out at the Agriculture Research Station of King Abdulaziz University during 2015/16 and 2016/17 seasons to optimize the productivity of grain sorghum under three irrigation water regimes and three humic acid (HA) levels. The first water regime was received the full irrigation water requirement (100% WR) while the second and the third water regimes received 80% and 60% from the full irrigation water requirements. Water regimes were investigated in main plots. The sub plots were three HA application levels namely: 5, 10 and 15 kg/ha. Each HA level for each plot was sown on soil surface and manually mixed with the upper 15 cm of soil surface before each planting date of the two. growing seasons. Results showed that, daily and seasonal water supplies were reduced by decreasing the applied water regimes. As irrigation water regime decreased grain yield and yield components significantly decreased. The average reduction over the two growing seasons in grain yield of sorghum were 4.7% in 80% WR and 25.5% in 60% WR when compared with full irrigation requirement treatment. Using HA by the level of 10 or 15 kg/ha as soil amendment improved yield production and yield components in grain sorghum. The increase in grain sorghum yield was 8% in 10 kg/ha level and 17.5 % in 15 kg/h HA level when compared with 5 kg/ha as an average over the two seasons. Irrigation water use efficiency (IWUE) was increased by decreasing irrigation water regime and increased by increasing HA application level. The IWUE of 80% WR with 15 kg/ha was significantly similar with 60% WR with 10 or 15kg/ha HA level. Finally, and according to the obtained results it can be concluded that 80% WR with 15 kg/ha HA reduced the grain yield by only 4.7 % while saved 20 % of irrigation water.

Keywords: *water stress, drip irrigation, soil conditioners, arid regions*

Introduction

Sorghum can grow as fodder and for human consumption in areas relay under water stress. Sorghum has a high concentration of potassium and starch, it is less acidifying and is easily absorbed and tolerated by the sick and diabetics, adults and even children. Sorghum is a substitute for wheat and is great for those requiring a gluten-free diet. Sorghum is naturally high in fiber and iron, with a high protein level as well. It is rich in antioxidants, which are believed to help lower the risk of cancer, diabetes, heart disease and some neurological diseases. It is also full of policosanols that may have an impact on human cardiac health. Sorghum can remain green in dry season when most of the other crops dry up because it can survive when the moisture levels are very low for any plant to grow. When freshly chopped, it can be given to cows, goats, sheep, and even chickens because it has the same energy levels as maize and other cereals. Sorghum produces much more forage than maize. This crop grows again after it is cut for use as fodder and harvesting of the grains, it therefore reduces the costs of replanting, land preparation and time. Forage sorghums use approximately 40-50% less water than corn to produce the same dry matter. (Miller & Stroup 2004).

Drought is one of the major limiting factors to agriculture, and considered as the most important cause of yield reduction in crop plants. However, grain sorghum tolerates and avoids drought more than many other cereal crops, but the drought response of sorghum does not come without a yield loss. Menezes *et al.,* (2015) evaluated forty-nine hybrids of grain sorghum under normal irrigation conditions or water stress in order to select those likely to be more tolerant of drought. Grain yield, weight of 1000 grains, harvest index, days to flowering, and plant height were affected by water stress; however, grain yield showed the largest relative reduction. Castro-Nava *et al.,* (2012) found that drought stress significantly reduced grain yield when it was applied at the flag leaf stage (24%) and at flowering (28%), but not when drought occurred at panicle initiation. Assefa *et al.,* (2010) found a 36% sorghum yield reduction when water stress occurred during the vegetative stage and more than 55% yield reduction with water stress occurring during the reproductive stage. Mahajan & Tuteja (2005) reported that water stress has diverse effects on physiology and development of sorghum that determines its final yield depending on the development stage at which stress occurs. Water stress occurring between pre- and post-flowering in sorghum decreases seed filling duration, seed size and number, thus leading to strong yield reduction or even total crop loss. The high tillering of forage sorghum provides compensation when the main stem is damaged by water stress, fostering yield stability in rainfed areas. Garofalo & Rinaldi (2013) found that sorghum biomass has a high potential productivity (3-4,000 g m^{-2}) of dry matter in Mediterranean environments if it is supplied with an adequate seasonal water amount, not less than 300 mm. However, sorghum showed a good adaptation to water stress.

Focusing on techniques that can improve water availability in summer growing season might be increased the production of summer crops. Because without any management rain or irrigation water may be percolating beyond root-zone, resulted in environmental consequences and diminishes water reserves. Many scientists, agronomists and farmers use humic acid (HA) for improving soil conditions and plant growth. Using such type of soil amendments help to conserve water in root-zone area. Therefore, water availability is increases due to the reductions in run-off and/or deep percolation that will ultimately cause increase in crop yield. Humic compounds can help to improve the soil structure by increasing the amount of pore space and enhancing the air exchange, water movement, water holding capacity and root growth. As a result, better drought resistance and reduction in water usage can be done (Khattak & Muhammad, 2006; Almarshadi & Ismail 2014 a and b). In plants, humic acids have positive effects on enzyme activity, plant nutrients, and growth stimulant and are considered as a "plant food". Humic acid contains 51% to 57% C, 4% to 6% N and 0.2% to 1% P and other micronutrients in minute amounts. Therefore, it acts as source of plant nutrients (Tejada &Gonzalez, 2003; Admas *et al.*, 2015). The contents of humic substance from plant nutrients act as organic fertilizers and are energy sources for bacteria, fungi, and earthworms that live in the soil. Beside their contents from nutrients, humic substances can chelate soil nutrients consequently improve nutrient uptake, especially phosphorous, sulfur and nitrogen because they act as a storehouse of N, P, S, and Zn (Davies *et al.*, 2004; Bandani *et al.*, 2014). Humic acid based fertilizers increase crop yield (Mohamed *et al.,* 2009). As being from the literature, HA considered a vital constituent and a friendly part of soil organic structure. Therefore, the main objectives of the current study were to optimize the productivity of grain sorghum as nutritious and forage crop in the soils treated with humic acid under the scarcity of irrigation water and to maximize irrigation water use efficiency.

Material and Methods

Experimental location, design and treatments

To achieve the above-mentioned objectives a field experiment was conducted at the Agriculture Research Station of King Abdulaziz University located at Hada Al-Sham, 110 km north east of Jeddah, KSA during the two growing seasons of 2015/2016 and 2016/2017. The soil texture of the experimental site was classified as sandy loam. The climate of the area was arid, with high temperatures during summer season. The design of the experiment was split plot with four replications. The main plots were for three irrigation water regimes. The first water regime was full irrigation water requirement and equal 100% of water requirements (100% WR). The second and third water regimes were 80% and 60% from the full irrigation water requirements (80% WR and 60% WR). The sub-plots were treated with a commercial product of HA, with a granular presentation and a purity of 90%, produced by Pioneers Chemicals (Saudi Arabia) in three proportions (5, 10 and 15 kg/ ha). Each humic acid level for each plot (area of the plot 2 m * 3 m = 6m^2) was sown on soil surface and manually mixed with the upper 15 cm of soil surface before each growing season. Surface drip irrigation method was used under the current study. Before installing irrigation networks, the experimental site was ploughed and leveled, and then the irrigation network was installed. The dripper lines were installed on soil surface at 40 cm between two adjacent dripper lines. The distance between drippers was 30 cm the type of the dripper line was RAIN

BIRD LD- 06- 12-1000 Landscape drip 0.9 G/h @12". Inlet pressure on each tape was about 1.5 bars. The system uses 125-micron disk filter. The water source was from the installed containers.

Water requirement calculation

The required amount of water for each water regime was calculated by CROPWAT model based on the average of 7 years metrological data collected from the weathering station presented in the experimental area as follows:

$$ETc = Kc \times ET0$$

Where:

ETc = Crop evapotranspiration (mm/day)

ET0 = Reference evapotranspiration (mm/day)

Kc = Crop Coefficient.

Reference evapotranspiration was calculated using Penman-monteith equation as described by Allen *et al*., (1998). Also, crop coefficient values for grain sorghum listed by Allen *et al*. (1998) was used. After water requirements were calculated, the control unit (timer) was adjusted for the required time to supply the calculated required amount of irrigation water. The required irrigation time for 100% WR treatments was calculated from the dripper discharge, the distance between drippers, and number of drip lines. As the daily water requirement was calculated in 100% WR treatments it reduced to be 80 % WR in the second treatment and to be 60% WR in the third treatment. Seasonal water supply for each crop was obtained by the summation of daily water supply. The soil preparation, planting date, seeding, fertilization, weeding, and harvesting were done according to El-Nakhlawy & Ghandorah (2010).

Data collection

Daily water supply was collected alone each growing season and then the seasonal water supply was calculated. For grain sorghum crop, the following traits were determined on 10 guarded random plants in each sub plot; heading date (no. of days from planting to 50% heading), plant height (cm). At harvesting, 100- grain weight (g), grain yield/ha (t), biomass yield /ha (t) and loss in yield in relation to irrigation water regimes were measured. Moreover, irrigation water use efficiency (IWUE) and water saving in relation to irrigation water regime were calculated.

Statistical Analysis

The obtained data in each experiment for each season were statistically analyzed through analysis of variance procedures to determine the significance of the treatments and the interactions. Means were separated and RLSD test was used to compare between the means after applying the statistical analysis assumptions according El-Nakhlawy (2010) using SAS (2006).

Results

Daily and seasonal water supply

Results of daily water supply are presented in Figure (1). The results show that, daily water supply for all investigated water regimes along the both growing seasons are increased gradually till reached maximum after about 90 and 60 days from planting in the first and the second seasons respectively. Then start decrease to reach minimum at harvesting. The highest water supply was recorded in 100% WR treatment followed by 80% WR and 60% WR treatment respectively.

Seasonal water supply was obtained from the summation of daily water supply along the growing season. The data are visualized in figure (2). Results clearly show that seasonal water supply was decreased by decreasing irrigation water regime. The least seasonal water supply obtained from 60% WR treatment followed by 80% WR treatment. The highest seasonal water supply was recorded in 100% WR treatment. The results also clearly indicated that, seasonal water supply of the second growing season was lower than that of the first growing season.

Agronomical traits of grain sorghum

Analysis of variance

Analysis of variance of the grain sorghum traits under the effects of irrigation water regimes, humic acid levels and their interactions during both growing seasons are presented in Tables (1 and 2).

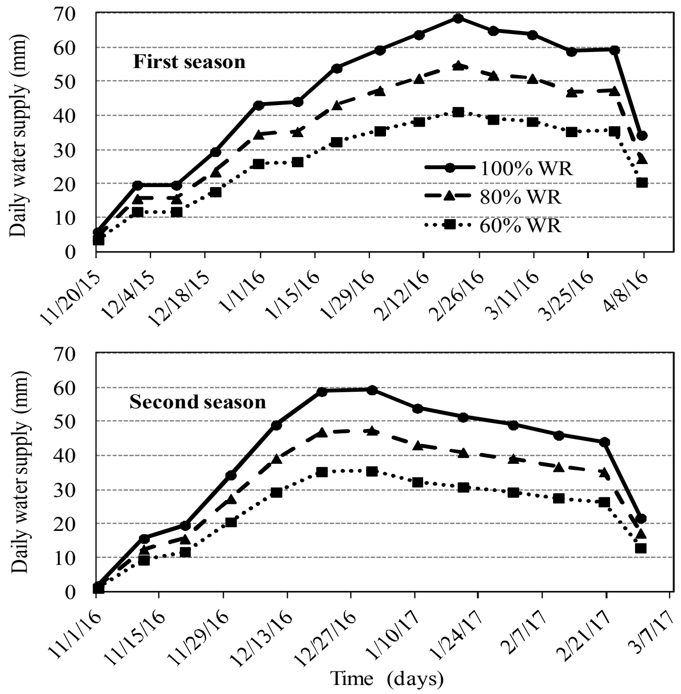

Figure 1. Daily water supply (mm) for grain sorghum under the effect of different irrigation water regimes during the growing seasons of 2015/16 and 2016/17.

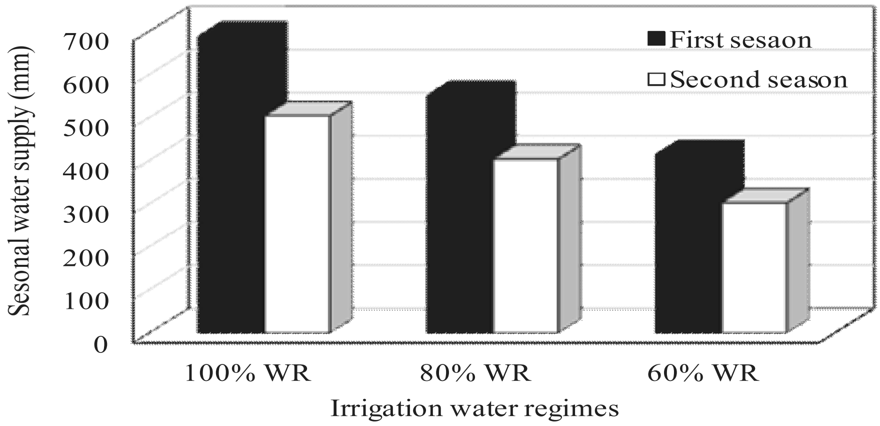

Figure 2. Seasonal water supply (mm) for grain sorghum under the effect of different irrigation water regimes during the growing seasons of 2015/16 and 2016/17.

The results of the analysis of variance showed significant effects for irrigation water regime, HA levels and their interaction on all studied grain sorghum traits and IWUE in both seasons.

Mean comparisons

Effect of water regimes

The statistical comparisons between the means of the studied traits under the three-irrigation water regimes in the two growing seasons using RLSD (0.05) for heading date, plant height and 100 grain weight are presented in Table (3). The results revealed that, heading date significantly decreased as water supply decreased in both seasons. Under 100% WR, heading dates were 54.08 and 55.60 days in the first and second seasons, respectively. Under the 60% WR heading dates were 49.58 and 51.43 days in the two seasons, respectively. Plant height means significantly decreased as water requirements decreased in both seasons. The tallest plants mean (124 and 130. 7 cm) were recorded in 100% WR followed by (98.0 and 114.96 cm) in 80% WR and (87.50 and 91.92 cm) in 60% WR for the two growing seasons, respectively. Similarly, 100-grain weight were significantly reduced by reducing water requirements where the highest 100-grain weight was recorded in 100% WR while the least was recorder in 60% WR treatment.

Table 1. Analysis of variance for heading date, plant height and 100-grain weight for grain sorghum during 2015/2016 and 2016/2017 seasons.

Source of Variation	df	Heading date (day)		Plant height (cm)		100-grain weight (g)	
		2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
Replicates	3	3.22 NS	1.33 NS	57.59 NS	33.95 NS	0.01 NS	0.24 NS
Water Regime (WR)	2	61.19**	29.36**	4237.0**	4653.24**	0.39**	0.48*
Error "a"	6	3.97	2.55	72.25	89.25	0.02	0.08
Humic acid levels(HA)	2	48.69**	8.03*	391.58*	142.27*	0.18**	0.18 *
WR * HA	4	10.98**	0436*	86.20*	120.47*	0.13*	0.16*
Error "b"	18	2.78	1.36	28.03	37.81	0.02	0.05

NS : not significant at at p ≤ 0.05, *,**: significant at at p ≤ 0.05 and at p ≤ 0.01, respectively.

Table 2. Analysis of variance for grain and biomass yields and IWUE for grain sorghum during 2015/2016 and 2016/2017 seasons.

Source of Variation	df	Grain yield (t/ha)		Biomass yield (t/ha)		IWUE kg/mm/ha	
		2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
Replicates	3	0.27 NS	0.13 NS	12.52 NS	21.36 NS	3.02 NS	1.67 NS
Water Regime (WR)	2	7.58**	1.44**	350.17**	184.40**	10.18**	10.99*
Error “a”	6	0.06	0.12	21.58	12.73	1.12	1.56
Humic acid levels (HA)	2	2.35**	0.46*	20.23*	0.86 NS	6.42**	5.09*
WR * HA	4	0.37*	0.36*	24.80*	27.86*	4.89**	4.22*
Error “b”	18	0.05	0.09	4.11	5.35	0.79	1.32

NS : not significant at at $p \leq 0.05$, *,**: significant at at $p \leq 0.05$ and at $p \leq 0.01$, respectively.

Results of grain and biomass yields and IWUE are presented in Table (4). Results revealed a reduction in grain yield by reducing the water requirements. The reduction in grain yield/ha recorded in the treatment of 80% WR was only 1.36% and 8% in the first and second season, respectively as compared with 100% WR. When water regime was reduced to be 60% WR the reduction in grain yield was sharply decreased to be 24.2% and 26.8% in the two seasons. Biomass yield/ha ranged from 21.06 to 10.44 t/ha in the first season and from 18.99 to 9.81 t/ha in the second season under 100% WR and 60% WR treatments, respectively.

Table 3. Means of heading date, plant height and 100-grain weight for grain sorghum under the effect of irrigation water regime in the growing seasons of 2015/16 and 2016/17.

Investigated water regimes	Heading date (day)		Plant height (cm)		100-grain weight (g)	
	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
100 % WR	54.08 a*	55.60 a	124.00 a	130.67 a	2.28 a	2.83 a
80 % WR	51.50 b	54.05 b	98.00 b	114.96 b	2.17a	2.42 b
60 % WR	49.58 b	51.43 c	87.50 c	91.92 c	1.93b	2.12 c
RLSD (0.05)	1.90	1.07	8.49	9.64	0.15	0.29

*Means followed by the same letter are not significantly different according to RLSD at $p \leq 0.05$.

Irrigation water use efficiency (IWUE) significantly increased by decreasing irrigation water regimes from 100% WR to 80% WR and 60% WR treatments. No significant differences were found between IWUE of 80% WR and 60% WR. The least IWUE (8.51 kg/mm/ha and 11.10 kg/mm/ha) were measured in 100% WR treatment in the first and second season, respectively. IWUE of 80% WR and 60% WR treatments were significantly similar. IWUE means were 10.50 and 10.79 kg/mm/ha in the first season and 12.76 and 13.55 kg/mm/ha in the second season for 80%WR and 60% WR treatments, respectively.

Table 4. Means of grain and biomass yields and IWUE for grain sorghum under the effect of irrigation water regime in the growing seasons of 2015/16 and 2016/17.

Investigated water regimes	Grain yield (t/ha)		Biomass yield (t/ha)		IWUE kg/mm/ha	
	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
100 % WR	5.87 a*	5.60 a	21.06 a	19.66 a	8.51 b	11.10 b
80 % WR	5.79 a	5.15 b	17.10 a	16.13 a	10.50a	12.76 a
60 % WR	4.45 b	4.10 c	10.44 b	9.81 b	10.79 a	13.55 a
RLSD (0.05)	0.23	0.35	4.64	3.56	1.19	1.27

*Means followed by the same letter are not significantly different according to RLSD at $p \leq 0.05$. IWUE: irrigation water use efficiency

Effect of humic acid levels

Means of heading date, plant height and 100- grain weight for grain sorghum traits as affected by HA levels in the two growing seasons are presented in (Table 5). Results revealed that, heading date delayed by 2.4 and 4.0 days in 10 and 15 kg/ha HA levels when compared with 5 kg/ha HA levels in the first season. In the second season no significantly difference was found between 10 and 15 kg/ha HA levels in the heading date but they significantly different from that of 5 kg/ha HA. Heading dates in the second season ranged from 52.25 days in 5 kg/ha HA to 54.95 days in 15 kg/ha HA levels. No significantly differences were found among plant height means under 10 and 15 kg/ha HA levels in both seasons. The tallest plants were recorded under the highest HA levels and the shortest were measured under the lowest HA levels.

Table 5. Means of heading date, plant height and 100-grain weight for grain sorghum under the effect of humic acid levels in the growing seasons of 2015/16 and 2016/17

Humic acid levels	Heading date (day)		Plant height (cm)		100-grain weight (g)	
	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
5 kg/ha	49.58 c*	52.25 b	97.08 b	109.50 b	2.03 b	2.36 b
10 kg/ha	52.00 b	54.45 a	104.00a	111.95ab	2.09 b	2.47 ab
15 kg/ha	53.58 a	54.95 a	108.42 a	116.10 a	2.26 a	2.55 a
RLSD (0.05)	1.24	0.88	5.28	5.52	0.12	0.20

*Means followed by the same letter(s) are not significantly different according to RLSD at $p \leq 0.05$

Plant height means ranged from 97.08, to 108.42 cm in the first season and from 109.50 cm to 116.10 cm in the second season. 100-grain weights were increased by increasing HA application levels however, the increase was significant only between 15 kg/ha and the other treatments. The increase in 100-grain weights of 80% WR and 60% WR treatments was statistically similar.

Results of the effect of humoc acid application levels on grain and biomass yields and IWUE are presented in Table (6). Results indicated that, grain yield/ha significantly increased by increasing HA levels in both seasons. The increases in grain yield were 9.35% and 18.09% in the first season and 8.35 and 16.8% in the second season for 10 and 15 kg/ha HA levels when compared with the grain yield of 5 kg/ha HA levels. No significantly differences were found in biomass yield/ha when comparing 10 and 15 kg/ha HA levels or when comparing 5 and 10 kg/ha HA levels in both seasons. Biomass yield/ha ranged from 15.19 to 17.17 t/ha in the first season and from 13.66 to 16.68 t/ha in the second season. No significant differences were found between IWUE means under 10 and 15 kg/ha HA levels or between 5 and 10 kg/ha HA levels in both seasons. The highest IWUE (10.82 and 13.44 kg/mm/ha) were obtained from the treatment of 15 kg/ha HA levels in the two seasons, respectively. The least significant IWUE was found in the treatment of 5 kg/ha HA levels with values of 9.05 and 11.51 kg/mm/ha in the first and second seasons, respectively.

Effect of the interaction between water regimes and humic acid levels

Means of heading date, plant height and 100-grain weight as affected by the interaction between the irrigation water regimes and humic acid levels in the two growing seasons are presented in Table (7). Results showed that, the highest heading dates in all interaction treatments were 57.24 and 56.80 days which recorded in 100% WR with 15 kg HA/ha in the first and the second seasons, respectively. No significant differences were found among heading dates of the treatments of 60% WR+ 15 kg/ha HA, 60% WR + 10 kg/ha HA, 80% WR + 10 kg/ha HA and 80% WR + 5 kg/ha HA in the first season. In the second season no significant differences were found between heading dates of 80% WR + 10 or 15 kg/ha HA and 100% WR + 5 kg/ha HA levels. Heading date ranged from 57.24 to 48.5 days in the first season and from 56.80 to 50 days in the second season.

Table 6. Means of grain and biomass yields and IWUE for grain sorghum under the effect of humic acid levels in the growing seasons of 2015/16 and 2016/17

Humic acid levels	Grain yield (t/ha)		Biomass yield (t/ha)		IWUE kg/mm/ha	
	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
5 kg/ha	4.92 c*	4.57 c	15.19 b	13.66 b	9.05 b	11.51 b
10 kg/ha	5.38 b	4.95 b	16.76 ab	15.27 ab	9.93 ab	12.46 ab
15 kg/ha	5.81 a	5.34 a	17.17 a	16.68 a	10.82 a	13.44 a
RLSD (0.05)	0.22	0.27	1.75	2.08	0.98	1.03

*Means followed by the same letter(s) are not significantly different according to RLSD at $p \leq 0.05$. IWUE: irrigation water use efficiency

Plant height means under the 9 interaction treatments showed that all HA levels for 100% WR produced the tallest plants in both seasons. No significant differences were found between the 80% WR + 15 kg/ha HA when compared with the treatments of 100% WR + 5 kg/ha HA levels in the second season. In the first season plant height means ranged from 128.26 cm to 83.77 cm while in the second season ranged from 134.24 cm to 88.50 cm under the treatments of 100% WR + 15 kg/ha HA and 60% WR + 5 kg/ha HA levels, respectively.

No significant difference was found between 100-grain weight under 100% WR with 5 kg/ha HA and 80% WR with 15 kg/ha HA. The 100-grain weight ranged from 2.40 g to 1.71g in the first season and from 2.92 to 2.01 in the second season under the treatments of 100% WR with 15 kg/ha HA and 60% WR with5 kg/ha HA levels, respectively.

Table 7. Means of heading date, plant height and 100-grain weight for grain sorghum under the effect of the interaction between irrigation water regimes and humic acid levels for the growing seasons of 2015/16 and 2016/17.

Irrigation water regime	Humic acid levels (kg/ha)	Heading date (day)		Plant height (cm)		100-grain weight (g)	
		2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
100 % WR	5	51.25	54.00	119.10	127.65	2.21	2.72
	10	53.76	56.00	124.75	130.11	2.24	2.85
	15	57.24	56.80	128.26	134.24	2.40	2.92
80 % WR	5	49.00	52.75	88.50	112.36	2.16	2.34
	10	51.27	53.85	96.53	114.27	2.12	2.42
	15	54.28	55.55	109.05	118.25	2.24	2.50
60 % WR	5	48.50	50.00	83.77	88.50	1.71	2.01
	10	51.00	51.80	90.78	91.46	1.94	2.13
	15	49.25	52.50	88.02	95.80	2.14	2.24
RLSD (0.05)		2.47	1.73	9.16	9.56	0.21	0.34

Concerning grain yield/ha under the effects of the interaction treatments, the results presented in Table (8) showed that, the highest grain yield/ha produced from 100% WR with 15 kg/ha HA and 80% WR with 15 kg/ha HA in the first season.

Table 8. Means of grain and biomass yields and IWUE for grain sorghum under the effect of the interaction between irrigation water regimes and humic acid levels for the growing seasons of 2015/16 and 2016/17

Irrigation water regime	Humic acid level (kg/ha)	Grain yield (t/ha)		Biomass yield (t/ha)		IWUE kg/mm/ha	
		2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
100 % WR	5	5.46	5.08	19.97	17.22	7.93	10.07
	10	5.89	5.61	21.21	19.74	8.56	11.12
	15	6.23	6.12	22.01	22.02	9.05	12.13
80 % WR	5	5.55	4.85	16.78	15.41	10.08	12.01
	10	5.74	5.14	17.62	15.58	10.34	12.73
	15	6.10	5.46	18.04	17.41	11.08	13.52
60 % WR	5	3.77	3.77	8.83	8.34	9.13	12.45
	10	4.50	4.10	11.03	10.48	10.90	13.54
	15	5.09	4.44	11.46	10.62	12.33	14.66
RLSD (0.05)		0.33	0.47	3.01	6.07	1.33	1.78

No significant differences were found between grain yield/ha under 80% WR with10 kg/ha or 15 kg/ha HA and 100% WR with 5 kg/ha HA. Grain yield/ha ranged from 6.23 to 3.77 t/ha in the first season and from 6.12 to 3.77 t/ha in the second season under the treatments of 100% WR with15 kg/ha HA and 60% WR with 5 kg/ha HA levels. Biomass yield/ha as affected by the interaction treatments showed insignificant differences among the treatments of the 100% WR with 5 kg/ha HA and 80% WR with 10 or 15 kg/ha HA in both seasons.

The biomass yield/ha ranged from 22.01 to 8.83 t/ha in the first season and from 22.02 to 8.34 t/ha in the second season under the treatment of 100% WR with 15 kg/ha HA and 60% WR with 5 kg/ha HA levles, respectively. Results of IWUE as affect by the interaction treatments indicated that, the highest IWUE was obtained from the treatment of 60% WR with 15 kg/ha HA and were 12.33 and 14.66 kg/mm/ha in the first and second seasons, respectively. The least IWUE were obtained from 100% WR treatment under 5 kg/ha HA application level.

Water saving in relation to water regimes

Results presented in table (9) for loss in yield and water saving in relation to applied water regimes indicated that, decreasing irrigation water regime from 100% WR to 80% WR reduced grain yield by only 1.36% in the first season and by 8.07% in the second season. Further reduction in water supply to be 60% of crop water requirement severely reduced grain yield by 24.19% in the first season and 26.78 in the second season. the reduction in grain yield was met by large amount of water saving. The saved water from crop water requirement reduction were 20% and 40% of irrigation water supply for 80% WR and 60% WR treatments respectively.

Table 9. Means of grain yield, total water supply, loss in yield and water saving of grain sorghum under the effects irrigation water regime during the growing seasons of 2015/2016 and 2016/2017.

Irrigation water regime (WR%)	Grain yield (kg/ha)		Total water supply (mm)		Loss in yield in relation to WR (%)		Water saving in relation to WR (%)	
	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
100 %WR	5870	5600	688.1	504.6	-	-	-	-
80 %WR	5790	5150	550.5	403.7	1.36	8.07	20.0	20.0
60 %WR	4450	4100	412.8	302.8	24.19	26.78	40.0	40.0

Discussions

Daily and season water supply

There were gradual reduction in daily and seasonal water supply as a result of reducing water regimes from 100% WR to 80% WR and 60% WR. This behavior is expected because the supplied water was only 80% and 60% of full water requirement (100% WR). Similar results were reported by, Ismail (2016); Ismail & Almarshadi (2013). Results also showed that, seasonal water supply during the second growing season was lower than that of the first growing season. The results might be attributed to the length of the growing season and the time of cultivation. The length of the second growing season was reduced by about one month compared to the first season. This reduction in growing season met by a reduction in seasonal water supply as clearly indicated by the results. Time of planting for the first season was at late November, while the planting time was at November 1st in the second growing season. As a result, the growth period during the first season was continue up to April but in the second growing season the growth period continue up to march. Due to the change in weather conditions especially temperature, relative humidity and wend speed the crop water requirement gradually increased from January to April, therefore the crop water requirement in the first season was higher than that of the second growing season. Irrigation amount varied with weather conditions, irrigation methods and levels (Ismail, 2012; Ismail & Almarshdi, 2013).

Effect of irrigation water regimes on yield and yield components

Drought stress caused a significant reduction in most of the studied grain sorghum characters. In cereals, yield losses are caused mainly by the reduction in starch accumulation during flowering or grain development (Barnabás *et al.,* 2008). The effects of drought on grain sorghum depended on when drought stress occurred during development (Castro-Nava *et al*., 2012).

Grain yield/ha significantly decreased as irrigation water requirement decreased from 100% to 80% and 60%. This significant decrease in the grain yield/ha might be due to the adversely effects of the irrigation water stress on the physiological, biochemical and metabolism procedures within the plants. Water stress reduces photosynthesis; the most important physiological processes that regulate development and productivity of plants (Menezes *et al*., 2015; Hamza *et al*., 2016). The reductions in seed yield components due to the decrease in irrigation water supply might be due to the decline in plant height, leaf gas exchange and leaf area, which resulted in reduction of photosynthetic level due to the unavailability of water nutrients in the soil (Ghaafar *et al*., 2014; Bandani *et al.,* 2014).

Effect of humic acid on yield and yield components

The obtained results showed an increase in the grain yield, yield components by increasing HA levels. The results might be due to the positive effects of HA in improving physical (Almarshadi & Ismail 2014b), chemical and biological properties of soils (Mikkelsen, 2005). The role of HA is well known in controlling soil-borne diseases, improving soil health, nutrient uptake by plants, mineral availability and fruit quality, etc (Mauromicale *et al*., 2011). Humic acid based fertilizers increase crop yield (Mohamed et al., 2009), stimulate plant enzymes/hormones and improve soil fertility in an ecologically and environmentally benign manner (Sarir *et al.,* 2005). Humic acid increased the level of adsorption of mineral ions on root surfaces and their penetration into the cells of the plant tissue (Sarwar *et al.,* 2014). Humic acid contains 51% to 57% C, 4% to 6% N and 0.2% to 1% P and other micronutrients in minute amounts. Therefore, it acts as source of plant nutrients (Tejada & Gonzalez., 2003). Beside their contents from nutrients, humic substances can chelate soil nutrients consequently improve nutrient uptake, especially phosphorous, sulfur and nitrogen because they act as a storehouse of N, P, S, and Zn (Davies *et al*., 2004).

Effect of water regimes and humic acid on irrigation water use efficiency

Results clearly showed an increase in IWUE by decreasing water regime and increasing HA application level. The increase in IWUR as a reduction of water regime might be due to several reasons. Water stress under low water regimes (80% WR and 60% WR) decreased losses especially runoff and deep percolation. IWUE was found to increase as a result of reducing deep percolation, canopy interception, soil type, and cultural and management practices (Ismail, 2016). Increasing yields under water stress treatment due to the wise use of irrigation water by investigated crops increase IWUE. Similar results reported by Lindenmayer *et al*. (2008), and Ismail (2016). Irrigation water use efficiency was also increased by increasing HA application level. The results might be due to the enhancement in retained soil water under high level of HA. Increasing soil water content increased yield production because the growth and yield is a great concern with improves soil conditions including water availability. All of the above mentioned factors increased yield production per unit of water consequently increased IWUE, (Madani *et al.,* 2012; Ismail

& Almarshadi 2013; Ismail 2016; Ihsan *et al.,* 2016).

Conclusions

The obtained results clearly revealed that, daily and seasonal water supplies were reduced by decreasing the applied water regimes. As irrigation water regime decreased yield and yield, components significantly decreased. The reduction in grain yield of sorghum were 4.7% and 25.5% for the same treatments over two growing seasons. Using HA by the levels of 10 or 15 kg/ha as soil amendment improved yield production and yield components in grain sorghum. The increase in grain sorghum yield was 8% and 17.5 % for the same treatments over the two growing seasons. No significant differences were showed between gain yield, biomass yield and yield components under 10 and 15 kg/ha HA levels. IWUE was increased by decreasing irrigation water regime and increased by increasing HA application level. The IWUE of 80% WR with 15 kg/ha was significantly similar with 60% WR with 10 or 15kg/ha HA levels. The results clearly indicated that 80% WR with 15 kg/ha HA treatment could be the best treatment to be applied under the condition of this experiment because it reduced the yield by about 1.36% - 8.07 % while saved 20 % of irrigation water.

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تعظيم انتاجية محصول الذرة الرفيعة (*Sorghum bicolor L.*) تحت الري الكامل والاجهاد المائي باستخدام حامض الهيوميك في المناطق القاحلة

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الملخص

اجريت تجربة حقلية في محطة البحوث الزراعية التابعة لجامعة الملك عبد العزيز بجده لتعظيم إنتاجية محصول الذرة الرفيعة تحت ثلاثة مستويات للري وثلاثة مستويات اضافة لحامض الهيوميك خلال موسمي ٢٠١٥/٢٠١٦ و ٢٠١٦/٢٠١٧. كان المستوي الاول للري هو اضافة كامل الاحتياجات المائية للمحصول (١٠٠٪ من الاحتياجات المائية) بينما كان مستوي اضافة مياه الري في المستوي الثاني والثالث هي ٨٠٪ و ٦٠٪ علي التوالي من كامل الاحتياجات المائية للمحصول. وتم دراسة هذه المستويات الثلاثة في القطع التجريبية الرئيسية لتصميم القطع المنشقة. تحت كل مستوي لمياه الري تم دراسة ثلاثة مستويات لاضافة حامض الهيوميك (٥ و ١٠ و ١٥ كجم / هكتار) حيث تم اضافة كل مستوي علي سطح القطعة التجريبية الفرعية ومن ثم خلطها يدويًا مع الطبقة السطحية من التربة بعمق ١٥ سم قبل بداية كل موسم زراعي واظهرت النتائج المتحصل عليها ما يلي:

١- تناقص إمدادات المياه اليومية والموسمية بتناقص مستويات مياه الري المضافة.

٢- ادى انخفاض مستويات مياه الري المضافة الي انخفاض معنوي في محصول الحبوب و مكونات المحصول حيث كان الانخفاض في محصول الحبوب كمتوسط عام لموسمي الزراعة هو ٤,٧ ٪ لمستوى الري ٨٠% و ٢٥,٥ ٪ لمستوي الري ٦٠% عند مقارنتها بمحصول الحبوب لمعاملة الري بكامل الاحتياجات المائية٠

٣- ادي اضافة حامض الهيوميك بمستويات ١٠ أو ١٥ كجم / هكتار كمحسن للتربة إلى تحسن في إنتاجية محصول الحبوب ومكونات المحصول للذرة الرفيعة. كانت الزيادة في محصول الحبوب حوالي كمتوسط عام خلال موسمي الزراعة هو ٨٪ للمستوي ١٠ كجم/هكتار حامض هيوميك ١٧,٥٪ للمستوي ١٥ كجم/هكتار عند مقارنتها بمعدل ٥ كجم/هكتار حامض هيوميك.

٤- زادت كفاءة استخدام مياه الري بانخفاض مستويات مياه الري المضافة وزيادة مستوي اضافة حامض الهيوميك حيث اظهرت النتائج ان كفاءة استخدام المياة باضافة ٨٠ ٪ من الاحتياجات المائية مع ١٥ كجم / هكتار تتشابه بشكل كبير مع اضافة ٦٠ ٪ من الاحتياجات المائية لكل من ١٠ أو ١٥ كجم / هكتار من حامض الهيوميك المضاف.

من نتائج هذه الدراسة المتحصل عليها يمكن التوصية بأن اضافة ٨٠٪ من الاحتياجات المائية مع ١٥ كجم / هكتار من حامض الهيوميك ادت الي انخفاض إنتاجية محصول الحبوب بحوالي ٤,٧% مع توفير ٢٠٪ من مياه الري.

الكلمات الدالة: الاجهاد المائي – الري بالتنقيط – محسنات التربة – المناطق القاحلة