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RESPONSE OF GRAIN SORGHUM (*SORGHUM BICOLOR*, L. MONECH) TO IRRIGATION, NITROGEN AND PLANT DENSITY UNDER NEW VALLEY CONDITIONS, EGYPT

Salem, Emad M.M.
Plant Production Department, Desert Research Center, 1 Mathaf El-Matareya St., El-Matareya 11753, Cairo, Egypt.
E-mail: emadmms@yahoo.com

The proper agronomical practices should be carefully chosen for optimizing grain sorghum productivity, particularly under limited-resources environments. Therefore, two field experiments were carried out in the Desert Research Center, Agriculture Experimental Station at El-Kharga Oasis, New Valley Governorate, during 2010 and 2011 growing seasons, to evaluate the effect of irrigation rate (5, 6 and 7 mm/fed/day); nitrogen fertilization rate (60, 80 and 100 kg N/fed) and plant density (17500, 23333 and 35000 plant/fed) on grain sorghum. Results showed that irrigation by 7 mm/fed/day was the potent treatment for increasing plant height, head length, head weight, weight of grains per head, seed index, grain yield, straw yield and biological yield compared to irrigation by 6 and 5 mm/fed/day. On the contrary, water use efficiency (WUE) and protein percentage were significantly decreased with increasing irrigation levels in both seasons. Adding 100 kg N/fed gave the maximum values of yield, yield components, water use efficiency and protein percentage compared to 80 and 60 kg N/fed in both seasons. Increasing plant density from 17500 to 35000 plant/fed caused significant increases in yield, yield attributes, water use efficiency and protein percentage, except for head weight, weight of grains per head and seed index in both seasons. Plots irrigated by 7 mm/fed and fertilized with 100 kg N/fed achieved the maximum values of grain, straw and biological yield/fed, when sorghum plants grown at high density (35000 plant/fed).

Keywords: grain sorghum, irrigation levels, N rates, plant density, WUE

New Valley region (located at the Western Desert of Egypt) is considered one of the promising locations by its oases for agricultural expansion; it represents 45% of Egypt area. Its weather is hot-dry and cultivation depends mainly on ground water, so sustainable agriculture requires application of quixotic cultural management for better use of land and water resources.

Grain sorghum as a staple food grain in several developing countries (Buah and Mwinkaara, 2009) is an important crop in arid and semiarid regions, because of its environmental adaptability. Also, sorghum is one of the most widely adapted forage crops to the arid and semi-arid tropics and dry-temperate areas of the world (Kidambi et al., 1990 and Blum, 2004). The productivity of grain sorghum could be increased by improving the cultural practices, such as irrigation regime, nitrogen fertilizer and plant density.

Irrigation water is a limiting factor in newly reclaimed areas as New Valley, due to the shortage in water resources, which causes serious crop damages. Therefore, there is a dire need to determine the optimum water requirement in order to reach the highest crop production with water rationalization. Availability of adequate amount of moisture at the critical stages of plant growth not only optimizes the metabolic process in plant cell, but also increases the effectiveness of the mineral nutrients applied to the crop, consequently any degree of water stress may produce deleterious effects on growth and yield of the crop. Previous studies on sorghum have shown that total leaf area and specific leaf area decreased under water stress, while, the root to shoot ratio increased (Munamava and Riddoch, 2001). A significant improvement in plant and dry matter formation measured as grain and straw yields was recorded with the increasing levels of irrigation (Abdel-Motagally, 2010). Afshar et al. (2014) stated that deficit irrigation reduced grain yield while, improving irrigation water use efficiency (WUE). Sher et al. (2013) noticed that the biomass traits and WUE were more influenced by water regimes, and similar trend was obtained by Fernandez et al. (2012).

On the other side, nitrogen is the key limiting factor and essential macronutrient required for most crops. Nitrogen is the most expensive fertilizer used to raise crop plants yield (Spiertz, 2010). However, sufficient or insufficient fertilization lead to economic losses and discharge an excessive amount of nitrogen in the nitrate from through washing (Henke et al., 2007). Asghari et al. (2006) reported that the increase in fertilization rate from 0 to 150 kg/ha increased significantly grain yield. Moreover, studies have shown that grain yield significantly differed at different nitrogen levels and grain yield increased at more nitrogen application rates (Mousavi et al., 2012; Zand and Shakiba, 2013; Abou-Amer and Kewan, 2014; Mahama et al., 2014 and Zand et al., 2014).

It is worth noticing that determining the optimal plant density that achieves the minimal intra-specific competition is essential to maximize the usage of water and nutrients per land unit area resulting in increasing productivity and more economical return under these conditions. In this connection, combined use of fertilizer and optimum plant density may increase food production and safe guard the environment for future generation (Buah and Mwinkaara, 2009). Reducing the distance between rows can also improve weed control by increasing crop competitiveness and reducing light transmittance to the soil (Andrade et al., 2002). Also, weed-grain sorghum competition is intensified by open canopy structures (Everaarts, 1993), while narrow row planting gives grain sorghum a competitive advantage over weeds (Walker and Buchanan, 1982). Javadi et al. (2005) noticed that higher plant density resulted in higher grain yield and biological yield. They stated that the increase in the density from 100000 to 260000 plants/ha resulted in 37.26 and 41.41% increase in grain and biological yield, respectively. Previous researches have indicated that grain yields generally increase as plant populations increase (Soleymani et al., 2011; Fernandez et al., 2012; Mousavi et al., 2012 and Zand and Shakiba, 2013).

In view of the above mentioned results, the aim of the present study is to determine the most appropriate irrigation water amount, nitrogen fertilization rate and optimum plant density on grain sorghum productivity under New Valley region of Egypt.

MATERIALS AND METHODS

1. Site Description

A two-year field experiment was carried out in the Desert Research Center (DRC), Agricultural Experimental Station at El-Kharga Oasis, New Valley Governorate, Egypt, during the two summer growing seasons of 2010 and 2011. The soil of the site is sandy clay loam containing 2.08% organic matter, pH of 8.5 and EC of 4.5 dS/m. The preceding crop was wheat in both seasons.

2. Experimental Treatments and Design

The study included three tested factors, i.e. irrigation, nitrogen and plant density. A split-split plot design with three replicates was used. Whereas, irrigation treatments were arranged in the main plots, nitrogen rates were distributed in the sub plots, and plant density patterns occupied the sub-sub plots. The experimental unit area was 10.5 m^2 containing five ridges (3.5 m length and 60 cm apart).

2.1. Irrigation treatments

Three irrigation levels were applied through gated pipe irrigation system (5, 6 and 7 mm/fed/day, which were equivalent to 2100, 2520 and 2940 m^3/fed, respectively). Well water was the source of irrigation with pH of 7.4 and EC of 1.09 dS/m, was used. Water amounts of irrigation levels were calculated based on evapotranspiration rate for each growth stage during each growing season. Irrigation water requirement for sorghum was calculated using the meteorological data at of the region as follows:

a. Crop evapotranspiration was calculated according to Doorenbos et al. (1977):

$$ET_c = ET_o \times K_c$$

Where:

ET_c = Crop evapotranspiration (mm/day),
ET_o = Reference evapotranspiration (mm/day),
K_c = Crop coefficient.

b. Applied irrigation water for sorghum crop was calculated according to Keller and Bliesner (1990):

$$IR = ET_c \times LR \times 4.2 / E_a$$

Where:

IR = Irrigation requirement (m^3/ha),
LR = Leaching requirement (%), (15%),
E_a = Water application WUE, (80% for gated pipe system).

2.2. Nitrogen rates

Nitrogen fertilizer at the rates of 60, 80 and 100 kg N/fed were applied in the form of ammonium nitrate (33.5% N) in two equal portions. The first portion was added on the 21st day after sowing, directly before thinning, and the second one on the 35th day after sowing.

2.3. Plant density patterns

Three plant densities, i.e. 17500, 23333 and 35000 plant/fed could be realized by planting sorghum in hills in one side of the ridge and the distances between hills were 40, 30 and 20 cm, respectively.

A grain sorghum cultivar (Dorado) was grown in May 19 and 22 in the first and second seasons, respectively. Phosphorus fertilizer was applied in the form of calcium super phosphate (15% P_2O_5) at a rate of 30 kg P_2O_5/fed during soil preparation. On the 21st day after sowing, plants were thinned to secure one plant per hill. Potassium fertilizer was applied in the form of potassium sulfate (48% K_2O) at a rate of 24 kg K_2O/fed at the 70th day after sowing. All other recommended agricultural practices were adopted throughout the two experimental seasons.

3. Sampling and Assessments

3.1. Yield traits

At harvest, ten guarded plants were taken randomly from each plot to measure plant height, head length, head weight, weight of grains/head and seed index. Moreover, whole plants of the plot were collected to measure grain, straw and biological yield/fed.

3.2. Grains nitrogen content

Total nitrogen was determined in grains using the modified micro kjeldahl method as described in A.O.A.C. (1995). Crude protein content % was calculated by multiplying the total nitrogen % by 6.25.

3.3. Water use efficiency (WUE)

Water use efficiency was calculated to evaluate the treatments, which have given the maximum yield per unit of water applied in the field. Sorghum grains moisture content was adjusted to be about 15.5% and the WUE was expressed as grain sorghum yield (kg)/applied water (m^3), according to Pene and Edi (1996).

4. Statistical Methods

All the obtained data of each season were exposed to the proper statistical analysis of variance according to Gomez and Gomez (1984). Least significance difference (LSD) test at 0.05 level of significance was used for the comparison between means.

RESULTS AND DISCUSSION

Available results in table (1, 2 and 3) explain that the main effect of each irrigation, N fertilization and plant density had marked impact on all yield and its components, WUE and protein percentage of grain sorghum.

1. Effect of Irrigation

As shown in table (1), plant height, head length, head weight per plant, weight of grains per head, seed index, grain yield, straw yield and biological yield were significantly enhanced with increasing irrigation levels in both seasons, while WUE and protein percentage were decreased. The highest values of sorghum yield and its components were achieved with irrigation by 7 mm/fed/day, whereas irrigation by 5 mm/fed/day was the inferior treatment. In this regard, the increments in grain sorghum yield and its components due to increasing irrigation water might be attributed to the beneficial effect of irrigation on growth and photosynthetic capacity. Consequently, more dry matter accumulated in yield components, which reflected on grain and biological yield/fed, Moreover, increasing irrigation water amount enhances the ability of plants to effectively utilize the environmental resources. This in turns increases the amount of metabolites synthesized (by plant). Water is generally considered as one of the limiting factors, which affects the physiological and biochemical processes influencing crop productivity. Moreover, water provides turgidity to the cell while water stress causes dehydration reducing the enlargement and

Table (1). Effect of irrigation treatments on grain sorghum yield and its components, WUE and protein percentage.

Irrigation treatments	Plant height (cm)	Head length (cm)	Head weight/ plant (g)	Weight of grains/ head (g)	Seed index (g)	Grain yield (kg/fed)	Straw yield (kg/fed)	Biological yield (kg/fed)	WUE (kg/m^3)	Protein (%)
2010 season										
I_1	118.1	19.15	53.04	38.59	21.81	2131.11	8419.6	10584.8	1.01	9.56
I_2	123.4	21.26	59.44	43.26	23.48	2380.37	9451.9	11832.2	0.94	9.08
I_3	127.3	22.00	60.81	44.30	23.85	2442.22	9633.3	12075.6	0.83	8.71
LSD (0.05)	1.62	0.37	0.34	0.41	0.30	71.98	64.74	90.1	0.03	0.05
2011 season										
I_1	114.8	18.22	55.22	39.26	21.59	2102.96	7880.4	9983.3	1.00	9.02
I_2	122.2	21.22	59.85	42.33	23.15	2115.93	8218.5	10334.4	0.84	8.87
I_3	127.4	21.93	62.11	44.33	23.16	2227.78	8488.9	10716.7	0.76	8.61
LSD (0.05)	0.90	0.68	1.49	0.62	0.47	13.72	71.3	82.0	0.02	0.03

I_1: 5 mm/fed/day, I_2: 6 mm/fed/day, I_3: 7 mm/fed/day, WUE: Water Use Efficiency, LSD: Least Significant Difference expansion of the cell, resulting in a reduction in leaf area. The reduction in leaf area certainly affects the overall growth of the crop (Swati et al., 1985). These results are in harmony with those of Munamava and Riddoch (2001), El-Sarag and Abu Hashem (2009), Abdel-Motagally (2010), Beheshti and Fard (2010), Jahanzad et al. (2013) and Afshar et al. (2014). Regarding WUE and protein percentage, irrigation by 5 mm/fed/day gave the highest significant values in both seasons (Table 1). While the lowest values were obtained at irrigation treatment by 7 mm/fed/day. Large quantity of irrigation water applied with the treatment of 7 mm/fed/day may cause reduction in WUE than adding 5 mm/fed/day. These results are in agreement with those stated by Abdalla et al. (1994), Mastrorilli et al. (1995), Abdel-Motagally (2010) and Afshar et al. (2014).

2. Effect of Nitrogen Fertilizer

Data of 2010 and 2011 seasons presented in table (2) clearly showed that abundant supply of nitrogen fertilizer markedly enhanced all studied traits. Adding 100 kg N/fed recorded the maximum values of yield and yield components, WUE and protein percentage. Such efficient treatment increased plant height, head length, head weight/plant, weight of grains/head, seed index, grain yield, straw yield, biological yield as well as WUE and protein percentage by 5.9, 4.6, 4.8, 5.0, 9.8, 9.8, 8.6, 8.5, 9.1 and 5.8%, respectively, in the first season and by 3.6, 4.3, 10.3, 6.6, 4.0, 9.9, 12.2, 11.4, 9.8 and 5.5%, respectively, in the second one, compared to adding 60 kg N/fed. The increments in yield and yield components as well as WUE and protein percentage by increasing nitrogen levels may be due to the fact that nitrogen fertilizer increased vegetative growth, leaf area and photosynthesis capacity whereby the grain sorghum plants efficiently used solar radiation for dry matter production. Additionally, nitrogen fertilization resulted in the increase in grain number per panicle and 1000-grain weight, which may be due to the increase in the fertile flowers and more appropriate nutritional conditions for grains during grain filling period by providing suitable conditions for plant cover formation, which reflected on grain yield and biomass/plant, and consequently increase yield and yield attributes. The obtained results are in agreement with those of and Asghari et al. (2006), Soleymani et al. (2011), Mousavi et al. (2012), Abou-Amer and Kewan (2014), Mahama et al. (2014) and Zand et al. (2014).

3. Effect of Plant Density

Planting 35000 plant/fed caused increments in all studied traits, except for head weight per plant, weight of grains/head and seed index in both seasons (Table 3). Such potent pattern increased each of plant height,

Table (2). Effect of nitrogen fertilizer on grain sorghum yield and its components, WUE and protein percentage.

Nitrogen fertilizer	Plant height (cm)	Head length (cm)	Head weight/ plant (g)	Weight of grains/ head (g)	Seed index (g)	Grain yield (kg/fed)	Straw yield (kg/fed)	Biological yield (kg/fed)	WUE (kg/m³)	Protein (%)
2010 season										
N_1	118.9	20.19	56.04	40.74	22.04	2192.22	8737.8	10964.1	0.88	8.86
N_2	123.9	21.11	58.52	42.59	22.93	2354.81	9276.7	11631.5	0.95	9.12
N_3	126.0	21.12	58.74	42.80	24.19	2406.67	9490.4	11897.0	0.96	9.37
LSD (0.05)	1.32	0.42	0.49	0.44	0.24	26.81	73.65	120.8	0.01	0.05
2011 season										
N_1	118.5	19.93	55.56	40.22	22.07	2033.70	7720.0	9753.7	0.82	8.63
N_2	122.7	20.67	60.37	42.81	22.85	2178.89	8205.9	10384.8	0.88	8.77
N_3	123.1	20.78	61.26	42.89	22.96	2234.07	8661.9	10895.9	0.90	9.10
LSD (0.05)	1.78	0.51	1.16	1.34	0.32	16.64	40.77	62.6	0.02	0.05

N_1: 60 kg N/fed, N_2: 80 kg N/fed, N_3: 100 kg N/fed, WUE: Water Use Efficiency, LSD: Least Significant Difference

Table (3). Effect of plant density on grain sorghum yield and its components, WUE and protein percentage.

Plant density	Plant height (cm)	Head length (cm)	Head weight/ plant (g)	Weight of grains/ head (g)	Seed index (g)	Grain yield (kg/fed)	Straw yield (kg/fed)	Biological yield (kg/fed)	WUE (kg/m^3)	Protein (%)
2010 season										
D_1	119.0	19.74	61.33	44.67	23.33	2155.56	8508.5	10664.1	0.87	8.99
D_2	123.2	21.00	58.26	42.37	23.15	2358.15	9358.9	11751.1	0.95	9.12
D_3	126.5	21.67	53.70	39.11	22.67	2440.00	9637.4	12077.4	0.98	9.24
LSD (0.05)	1.53	0.45	0.56	0.45	0.39	27.21	68.3	99.7	0.01	0.04
2011 season										
D_1	118.4	19.74	64.67	45.59	23.11	2025.56	7780.0	9805.6	0.82	8.78
D_2	122.1	20.59	60.00	42.41	22.81	2159.26	8234.8	10394.1	0.87	8.83
D_3	123.9	21.04	52.52	37.93	21.96	2261.85	8572.9	10834.8	0.91	8.89
LSD (0.05)	1.44	0.46	1.06	0.98	0.42	16.47	43.81	59.9	0.01	0.04

D_1: 17500 plant/fed, D_2: 23333 plant/fed, D_3: 35000 plant/fed, WUE: Water Use Efficiency, LSD: Least Significant Difference head length, grain yield, straw yield and biological yield as well as WUE and protein percentage by 6.3, 9.8, 13.2, 13.3, 13.3, 12.6 and 2.8% in the first season and 4.7, 6.6, 11.7, 10.2, 10.5, 11.0 and 1.3% in the second one, respectively, as compared with the pattern of 17500 plant/fed. These enhancements might be due to that the high density under 35000 plant/fed patterns would allow more efficient available sunlight, moisture and nutrients, besides it saved the maximum number of harvested plants/unit area. It has been reported that the yield response to narrow rows in grain sorghum is affected by many environmental, spatial and temporal field interactions (Andrade et al., 2002 and Thelen, 2006). These results are in harmony with those obtained by Javadi et al. (2005), Lak et al. (2006), Soleymani et al. (2011), Fernandez et al. (2012), Mousavi et al. (2012) and Zand et al. (2014).

Contrariwise, planting 17500 plant/fed increased head weight by 14.2 and 23.1%, weight of grains/head by 14.2 and 20.2% and seed index by 2.9 and 5.2%, in the first and second seasons, respectively, compared with 35000 plant/fed treatment. These results are supported by findings of Mousavi et al. (2012) and Zand et al. (2014). The superiority of 17500 plant/fed treatment in head weight, weight of grains/head and seed index may be due to low intra-specific competition among grain sorghum plants under low plant population in turn enhancing the most plant growth traits consequently. This enables plants to make good use of the environmental resources as water and nutrients, which is reflected on yield components.

4. Effect of Interactions

First order interactions, i.e. irrigation × nitrogen; irrigation × plant density and nitrogen × plant density are presented in table 4, 5 and 6 as well as the second order interaction, i.e. irrigation × nitrogen × plant density is shown in table 7 and 8.

4.1. Irrigation × nitrogen

Data in table (4) show the impact of the interaction between irrigation levels and nitrogen treatments on yield and its components as well as, WUE and protein percentage in both seasons. The combination of irrigation by 7 mm/fed/day with adding 100 kg N/fed gave the highest values of plant height, head length and weight, weight of grains/head, seed index, grain yield, straw yield and biological yield in both seasons. While, the combination of irrigation by 5 mm/fed/day with adding 80 kg N/fed recorded the maximum values of WUE in both seasons. Also, the same irrigation treatment with adding 100 kg N/fed was the best treatment for improving protein percentage in both seasons.

4.2. Irrigation × plant density

With exception of weight of grains/head and seed index, considerable effect of the interaction between irrigation levels × plant density on all yield and yield traits as well as WUE and protein percentage were obtained (Table 5). In this concern, irrigation by 7 mm/fed/day with plant density of 35000 plant/fed recorded the maximum values for plant height, head length, grain yield, straw yield and biological yield in both seasons. Additionally, irrigation by 7 mm/fed with plant density of 17500 plant/fed was the superior combination for promoting head weight in both seasons. Moreover, irrigation by 5 mm/fed/day with plant density of 35000 plant/fed secured the maximum WUE and protein percentage in both seasons. These results are in similar trend with those of Steiner (1986) and Sanabria et al. (1995).

4.3. Nitrogen × plant density

The interaction between nitrogen fertilizer and plant density treatment showed a remarkable effect on grain, straw and biological yield/fed. Whereas, no significant differences were obtained in plant height, head length, seed index and protein percentage in both seasons (Table 6). Herein, the effective combination was nitrogen fertilizer at 100 kg N/fed with plant density of 35000 plant/fed for increasing grain, straw and biological yield/fed. Moreover, combination of adding 100 kg N/fed with plant density of 17500 plant/fed recorded the maximum values of head weight/plant and weight of grains/head in the first season. Also, adding 80 kg N/fed with plant density of 35000 plant/fed was the most effective for enhancing WUE in the first season. These results are in harmony with those obtained by Zand and Shakiba (2013) and Zand et al. (2014).

4.4. Irrigation × nitrogen × plant density

Head weight/plant and grain, straw and biological yield/fed were significantly affected by second order interaction (among irrigation levels, nitrogen fertilizer and plant density). While, plant height has not been affected in both seasons (Table 7 and 8). Therein, in the first season, plots irrigated by 7 mm/fed/day and 100 kg nitrogen recorded the highest values of head weight, seed index, grain, straw and biological yield/fed when grain sorghum plants were planted at high density (35000 plant/fed). In the second season, irrigation by 7 mm/fed/day x 100 kg nitrogen x 35000 plant/fed showed the maximum values of grain, straw and biological yield/fed. While, the heaviest head was gained from irrigation by 7 mm/fed/day x 100 kg nitrogen x 17500 plant/fed. Moreover, the effective combinations for improving WUE and protein percentage were possessed with irrigation by 5 mm/fed × 80 kg N/fed × plant density of 17000 plant/fed and irrigation by 5 mm/fed × 100 kg N/fed × plant density of 35000 plant/fed, respectively, in the first season only.

Table (4). Effect of irrigation treatments and nitrogen fertilizer interaction on grain sorghum yield and its components, WUE and protein percentage.

I	N	Plant height (cm)	Head length (cm)	Head weight/ plant (g)	Weight of grains/ head (g)	Seed index (g)	Grain yield (kg/fed)	Straw yield (kg/fed)	Biological yield (kg/fed)	WUE (kg/m³)	Protein (%)
2010 season											
I_1	N_1	117.1	19.11	53.44	38.78	21.11	2013.33	8072.2	10187.8	0.96	9.15
	N_2	119.9	19.89	53.89	39.33	21.89	2215.56	8705.6	10921.1	1.06	9.66
	N_3	116.1	18.44	51.78	37.67	22.44	2164.44	8481.1	10645.6	1.03	9.88
I_2	N_1	120.0	20.44	56.11	40.78	22.89	2255.56	8998.9	11254.4	0.90	8.80
	N_2	123.3	21.56	61.22	44.56	23.44	2400.89	9528.9	11937.8	0.96	9.04
	N_3	126.9	21.78	61.00	44.44	25.22	2476.67	9827.8	12304.4	0.98	9.40
I_3	N_1	119.6	21.00	58.56	42.67	22.11	2307.78	9142.2	11450.0	0.78	8.64
	N_2	128.3	21.89	61.11	44.56	23.44	2440.00	9595.6	12035.6	0.83	8.67
	N_3	134.0	23.11	62.78	45.67	24.89	2578.89	10162.2	12741.1	0.88	8.82
LSD (0.05)		2.29	0.73	0.85	0.77	0.42	46.43	127.6	209.2	0.02	0.08
2011 season											
I_1	N_1	114.4	18.56	53.00	38.89	21.33	2017.78	7458.9	9476.7	0.96	8.70
	N_2	116.3	18.89	56.56	40.11	21.56	2151.11	7932.2	10083.3	1.04	8.94
	N_3	113.7	17.22	56.11	38.78	21.89	2140.00	8250.0	10390.0	1.02	9.41
I_2	N_1	119.6	20.33	56.44	40.44	22.00	2013.33	7691.1	9704.4	0.80	8.68
	N_2	123.1	21.67	62.11	44.33	23.56	2125.56	8202.2	10327.8	0.84	8.80
	N_3	123.9	21.77	61.00	42.22	23.67	2208.89	8762.2	10971.1	0.88	9.12
I_3	N_1	121.6	20.89	57.22	41.33	22.33	2070.00	8010.0	10080.0	0.70	8.51
	N_2	128.8	21.78	62.89	44.00	23.44	2260.00	8483.3	10743.3	0.77	8.56
	N_3	131.8	23.11	66.22	47.67	23.89	2353.33	8973.3	11326.7	0.80	8.76
LSD (0.05)		3.07	0.89	2.01	2.32	0.56	28.83	70.61	108.4	0.03	0.09

I_1: 5 mm/fed/day, I_2: 6 mm/fed/day, I_3: 7 mm/fed/day, N_1: 60 kg N/fed, N_2: 80 kg N/fed, N_3: 100 kg N/fed, WUE: Water Use Efficiency, LSD: Least Significant Difference

Table (5). Effect of irrigation treatments and plant density interaction on grain sorghum yield and its components, WUE and protein percentage.

I	D	Plant height (cm)	Head length (cm)	Head weight/ plant (g)	Weight of grains/ head (g)	Seed index (g)	Grain yield (kg/fed)	Straw yield (kg/fed)	Biological yield (kg/fed)	WUE (kg/m^3)	Protein (%)
2010 season											
	D$_1$	115.7	18.89	56.44	41.11	22.78	2020.0	7964.4	9984.4	0.96	9.37
I$_1$	**D$_2$**	119.1	19.33	54.00	39.22	22.00	2162.22	8566.7	10832.1	1.03	9.59
	D$_3$	119.3	19.22	48.67	35.44	21.66	2211.11	8727.8	10938.9	1.05	9.73
	D$_1$	118.4	19.89	62.67	45.67	24.10	2193.33	8691.1	10884.4	0.87	8.96
I$_2$	**D$_2$**	124.3	21.78	60.11	43.67	24.00	2435.56	9688.9	12124.4	0.97	9.07
	D$_3$	127.4	22.11	55.56	40.44	23.56	2512.22	9975.6	12487.8	1.00	9.22
	D$_1$	122.9	20.44	64.89	47.22	23.22	2253.33	8870.0	11123.3	0.77	8.65
I$_3$	**D$_2$**	126.2	21.89	60.67	44.22	23.44	2476.67	9821.1	12297.8	0.84	8.70
	D$_3$	132.8	23.67	56.89	41.44	23.78	2596.67	10208.9	12805.6	0.88	8.77
LSD (0.05)		2.65	0.77	0.97	NS	NS	47.12	118.2	172.6	0.02	0.06
2011 season											
	D$_1$	113.9	18.22	61.22	42.89	22.22	1995.56	7703.3	9698.9	0.95	8.98
I$_1$	**D$_2$**	115.2	18.32	56.00	39.11	21.67	2117.78	7875.6	9993.3	1.01	9.00
	D$_3$	115.3	18.25	48.44	35.78	20.89	2195.56	8062.2	10257.8	1.05	9.07
	D$_1$	118.2	20.33	64.56	45.44	23.89	1994.44	7674.4	9668.9	0.79	8.78
I$_2$	**D$_2$**	122.4	21.33	61.11	43.44	23.22	2134.44	8291.1	10425.6	0.85	8.88
	D$_3$	125.9	22.00	53.89	38.11	22.33	2218.89	8690.0	10908.9	0.88	8.94
	D$_1$	123.1	20.67	68.22	48.44	23.22	2086.67	7962.2	10048.9	0.71	8.57
I$_3$	**D$_2$**	128.4	22.22	62.89	44.67	23.56	2225.56	8537.8	10763.3	0.76	8.60
	D$_3$	130.6	22.89	55.22	39.89	22.67	2371.11	8966.7	11337.8	0.81	8.65
LSD (0.05)		2.49	0.79	1.84	NS	NS	28.52	75.89	103.8	0.01	0.04

I_1: 5 mm/fed/day, I_2: 6 mm/fed/day, I_3: 7 mm/fed/day, D_1: 17500 plant/fed, D_2: 23333 plant/fed., D_3: 35000 plant/fed,
WUE is Water Use Efficiency, LSD: Least Significant Difference

Table (6). Effect of nitrogen fertilizer and plant density interaction on grain sorghum yield and its components, WUE and protein percentage.

N	D	Plant height (cm)	Head length (cm)	Head weight/ plant (g)	Weight of grains/ head (g)	Seed index (g)	Grain yield (kg/fed)	Straw yield (kg/fed)	Biological yield (kg/fed)	WUE (kg/m³)	Protein (%)
						2010 season					
	D_1	114.8	19.00	60.44	44.00	22.11	2015.56	8002.2	10017.8	0.81	8.73
N_1	D_2	119.3	20.22	57.00	41.33	22.33	2254.44	9016.7	11373.3	0.90	8.88
	D_3	122.6	21.33	50.67	36.89	21.67	2306.67	9194.4	11501.1	0.92	8.97
	D_1	119.7	20.11	61.67	44.89	23.44	2193.33	8625.6	10818.9	0.88	9.00
N_2	D_2	123.6	21.44	59.33	43.22	22.78	2360.00	9375.6	11735.6	0.95	9.14
	D_3	128.3	21.78	55.22	40.33	22.56	2502.22	9828.9	12331.1	1.01	9.23
	D_1	122.6	20.11	61.89	45.11	24.44	2257.78	8897.8	11155.6	0.91	9.23
N_3	D_2	126.8	21.33	58.44	42.56	24.33	2460.00	9684.4	12144.6	0.98	9.35
	D_3	128.7	21.89	55.22	40.11	23.78	2511.11	9888.9	12400.1	1.00	9.52
LSD (0.05)		NS	NS	0.97	0.77	NS	47.12	118.2	172.6	0.02	NS
						2011 season					
	D_1	115.7	19.00	62.11	44.22	22.33	1922.22	7470.0	9392.2	0.78	8.59
N_1	D_2	119.1	20.00	56.67	40.67	22.44	2056.67	7707.8	9764.4	0.83	8.65
	D_3	120.8	20.78	47.89	35.78	21.44	2122.22	7982.2	10104.4	0.86	8.64
	D_1	120.2	19.89	65.67	45.78	23.11	2046.67	7774.4	9821.1	0.83	8.71
N_2	D_2	121.9	20.89	61.22	43.22	23.00	2181.11	8266.7	10447.8	0.88	8.72
	D_3	126.1	21.56	54.22	39.44	22.44	2308.89	8576.7	10885.6	0.93	8.87
	D_1	119.3	20.33	66.22	46.78	23.89	2107.78	8095.6	10203.3	0.85	9.02
N_3	D_2	124.9	20.78	62.11	43.33	23.00	2240.00	8730.0	10970.0	0.90	9.10
	D_3	125.1	20.89	55.44	38.56	22.00	2354.44	9160.0	11514.4	0.95	9.16
LSD (0.05)		NS	NS	NS	NS	NS	28.52	75.89	103.8	NS	NS

N_1: 60 kg N/fed, N_2: 80 kg N/fed, N_3: 100 kg N/fed, D_1: 17500 plant/fed, D_2: 23333 plant/fed, D_3: 35000 plant/fed, WUE: Water Use Efficiency, LSD: Least Significant Difference

Table (7). Effect of irrigation treatments, nitrogen fertilizer and plant density interaction on grain sorghum yield and its components, WUE and protein percentage (2010 season).

I	N	D	Plant height (cm)	Head length (cm)	Head weight/ plant (g)	Weight of grains/ head (g)	Seed index (g)	Grain yield (kg/fed)	Straw yield (kg/fed)	Biological yield (kg/fed)	WUE (kg/m³)	Protein (%)
I_1	N_1	D_1	113.0	18.33	57.33	41.67	21.67	1873.33	7493.3	9366.7	0.89	8.90
		D_2	119.0	19.33	54.33	39.33	21.33	2073.33	8340.0	10413.0	0.99	9.20
		D_3	119.3	19.67	48.67	35.33	20.33	2093.33	8383.3	10476.7	1.00	9.35
	N_2	D_1	116.7	19.33	57.00	41.67	23.33	2080.00	8100.0	10180.0	0.99	9.55
		D_2	119.3	20.00	55.33	40.33	21.67	2233.33	8500.0	10733.3	1.06	9.68
		D_3	123.7	20.33	49.33	36.00	20.67	2233.33	9166.7	11500.0	1.11	9.74
	N_3	D_1	117.3	19.00	55.00	40.00	23.33	2106.67	8300.0	10406.7	1.00	9.64
		D_2	119.0	18.67	52.33	38.00	23.00	2180.00	8510.0	10690.0	1.04	9.89
		D_3	115.0	17.67	48.00	35.00	21.00	2206.67	8633.3	10840.0	1.05	10.10
I_2	N_1	D_1	115.0	18.67	61.33	44.67	22.33	2060.00	8246.7	10306.7	0.82	8.71
		D_2	120.3	21.00	57.67	41.67	23.33	2313.33	9250.0	11563.3	0.92	8.79
		D_3	124.7	21.67	49.33	36.00	23.00	2393.33	9500.0	11893.3	0.95	8.89
	N_2	D_1	119.3	20.33	62.67	45.67	24.33	2213.33	8726.7	10940.0	0.88	8.87
		D_2	123.3	22.33	62.00	45.00	23.33	2466.67	9766.7	12233.3	0.98	9.05
		D_3	127.3	22.00	59.00	43.00	22.67	2546.67	10093.3	12640.0	1.01	9.21
	N_3	D_1	121.0	20.67	64.00	46.67	25.22	2306.67	9100.0	11406.7	0.92	9.29
		D_2	129.3	22.00	60.67	44.33	25.11	2526.67	10050.0	12576.7	1.00	9.37
		D_3	130.3	22.67	58.33	42.33	25.00	2596.67	10333.3	12930.0	1.03	9.55
I_3	N_1	D_1	116.3	20.00	62.67	45.67	22.33	2113.33	8266.7	10380.0	0.72	8.59
		D_2	118.7	20.33	59.00	43.00	22.33	2376.67	9460.0	11836.7	0.81	8.63
		D_3	123.7	22.67	54.00	39.33	21.67	2433.33	9700.0	12133.3	0.83	8.68
	N_2	D_1	123.0	20.67	65.33	47.33	22.67	2286.67	9050.0	11336.7	0.78	8.58
		D_2	128.0	22.00	60.67	44.33	23.33	2380.00	9510.0	11890.0	0.81	8.69
		D_3	134.0	23.00	57.33	42.00	24.33	2653.33	10226.7	12880.0	0.90	8.73
	N_3	D_1	129.3	20.67	66.67	48.67	24.67	2360.00	9293.3	11653.3	0.80	8.77
		D_2	132.0	23.33	62.33	45.33	24.67	2673.33	10493.3	13166.7	0.91	8.78
		D_3	140.7	25.33	59.33	43.00	25.33	2703.33	10700.0	13403.3	0.92	8.90
LSD (0.05)			NS	1.34	1.68	1.34	1.17	81.62	204.8	299.0	0.03	0.11

I_1: 5 mm/fed/day, I_2: 6 mm/fed/day, I_3: 7 mm/fed/day, N_1: 60 kg N/fed, N_2: 80 kg N/fed, N_3: 100 kg N/fed, D_1 : 17500 plant/fed, D_2: 23333 plant/fed, D_3: 35000 plant/fed, WUE: Water Use Efficiency, LSD: Least Significant Difference

Table (8). Effect of irrigation treatments, nitrogen fertilizer and plant density interaction on grain sorghum yield and its components, WUE and protein percentage (2011 season).

I	N	D	Plant height (cm)	Head length (cm)	Head weight/ plant (g)	Weight of grains/ head (g)	Seed index (g)	Grain yield (kg/fed)	Straw yield (kg/fed)	Biological yield (kg/fed)	WUE (kg/m³)	Protein (%)
I_1	N_1	D_1	112.0	18.00	61.00	43.33	22.67	1906.67	7293.3	9200.0	0.91	8.70
		D_2	115.0	18.33	52.00	37.00	22.33	2066.67	7476.7	9543.3	0.98	8.74
		D_3	116.3	19.33	46.00	36.33	20.67	2080.00	7606.7	9686.7	0.99	8.66
	N_2	D_1	116.3	18.67	61.67	43.33	21.67	2026.67	7700.0	9726.7	0.97	8.90
		D_2	115.3	19.00	58.33	40.33	21.33	2153.33	7916.7	10070.0	1.03	8.82
		D_3	117.3	19.00	48.33	36.67	21.67	2273.33	8180.0	10453.3	1.08	9.10
	N_3	D_1	113.3	18.00	61.00	42.00	22.33	2053.33	8116.7	10170.0	0.98	9.34
		D_2	115.3	17.33	57.67	40.00	21.33	2133.33	8233.3	10366.7	1.02	9.44
		D_3	112.3	16.33	51.00	34.33	20.33	2233.33	8400.0	10633.3	1.06	9.46
I_2	N_1	D_1	117.0	19.67	62.33	44.00	22.33	1900.00	7400.0	9300.0	0.75	8.58
		D_2	119.7	20.33	58.67	42.67	22.33	2013.33	7566.7	9580.0	0.80	8.71
		D_3	122.0	21.00	48.33	34.67	21.33	2126.67	8106.7	10233.3	0.84	8.74
	N_2	D_1	118.7	20.67	66.00	46.67	24.62	2000.00	7506.7	9506.7	0.79	8.74
		D_2	121.7	21.67	62.00	44.67	23.33	2163.33	8350.0	10513.3	0.86	8.78
		D_3	129.0	22.67	58.33	41.67	22.67	2213.33	8750.0	10963.3	0.88	8.88
	N_3	D_1	119.0	20.67	65.33	45.67	24.64	2083.33	8116.7	10200.0	0.83	9.01
		D_2	126.0	22.00	62.67	43.00	24.00	2226.67	8956.7	11183.3	0.88	9.13
		D_3	126.7	22.33	55.00	38.00	23.00	2316.67	9213.3	11530.0	0.92	9.21
I_3	N_1	D_1	118.0	19.33	63.00	45.33	22.00	1960.00	7716.7	9676.7	0.67	8.49
		D_2	122.7	21.33	59.33	42.33	22.67	2090.00	8080.0	10170.0	0.71	8.51
		D_3	124.0	22.00	49.33	36.33	22.33	2160.00	8233.3	10393.3	0.73	8.52
	N_2	D_1	125.7	20.33	69.33	47.33	23.00	2113.33	8116.7	10230.0	0.72	8.50
		D_2	128.7	22.00	63.33	44.67	24.33	2226.67	8533.3	10760.0	0.76	8.56
		D_3	132.0	23.00	56.00	40.00	23.00	2440.00	8800.0	11240.0	0.83	8.62
	N_3	D_1	125.7	22.33	72.33	52.67	24.67	2186.67	8053.3	10240.0	0.74	8.72
		D_2	134.0	23.33	66.00	47.00	23.67	2360.00	9000.0	11360.0	0.80	8.74
		D_3	135.7	23.67	60.33	43.33	22.67	2513.33	9866.7	12380.0	0.85	8.82
LSD (0.05)			NS	NS	3.19	NS	NS	49.40	131.44	179.8	NS	NS

I_1: 5 mm/fed/day, I_2: mm/fed/day, I_3: 7 mm/fed/day, N_1: 60 kg N/fed, N_2: 80 kg N/fed, N_3: 100 kg N/fed, D_1: 17500 plant/fed, D_2: 23333 plant/fed, D_3: 35000 plant/fed, WUE: Water Use Efficiency, LSD: Least Significant Difference

CONCLUSION

It could be concluded that under the conditions of New Valley region, application of 7 mm/fed (2940 m^3/fed) x adding 100 kg N/fed x plant density of 35000 plant/fed could be recommended for good use of environmental resources and maximizing grain sorghum productivity.

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إستجابة الذرة الرفيعة لماء الري، النيتروجين والكثافة النباتية تحت ظروف الوادي الجديد، مصر

عماد محمد محمد سالم
قسم الإنتاج النباتي، مركز بحوث الصحراء، المطرية، القاهرة، مصر

إن الممارسات الزراعية المناسبة يجب إختيارها بعناية لتحقيق أقصى إنتاجية من حبوب الذرة الرفيعة خاصة في ظل بيئات محدودة الموارد. لذلك أجريت تجربتان حقليتان في مركز بحوث الصحراء، بمحطة التجارب الزراعية بواحة الخارجة بمحافظة الوادي الجديد، خلال عامي ٢٠١٠ و٢٠١١، لتقييم تأثير كميات مياه الري (٥، ٦، ٧ مم/فدان/يوم) ومعدل التسميد النيتروجيني (٦٠، ٨٠، ١٠٠ كجم نيتروجين/فدان) والكثافة النباتية (١٧٥٠٠، ٢٣٣٣٣، ٣٥٠٠٠ نبات/فدان) على حبوب الذرة الرفيعة.

أظهرت النتائج أن الري بمعدل ٧ مم/فدان/يوم كان المعاملة الفعالة لزيادة إرتفاع النبات، طول القنديل، وزن القنديل، وزن الحبوب في القنديل، دليل البذور، محصول الحبوب، محصول القش والمحصول البيولوجي مقارنة مع الري بمعدل ٦ و٥ مم/ فدان/ يوم. على العكس من ذلك، فقد إنخفضت كفاءة إستخدام الماء ونسبة البروتين معنويًا مع زيادة مستويات الري في كلا الموسمين. حققت إضافة ١٠٠ كجم نيتروجين/فدان أعلى القيم للمحصول ومكوناته، وكفاءة إستخدام الماء ونسبة البروتين، مقارنة مع إضافة ٨٠ و٦٠ كجم نيتروجين/فدان في كلا الموسمين. أدت زيادة الكثافة النباتية من ١٧٥٠٠ إلى ٣٥٠٠٠ نبات/فدان إلى زيادات معنوية في المحصول ومكونات المحصول وكفاءة إستخدام الماء ونسبة البروتين، بإستثناء وزن القنديل ووزن الحبوب بالقنديل ودليل البذور في كلا الموسمين. سجلت القطع التجريبية المروية بمقدار ٧ مم/فدان/يوم وسُمدت بمعدل ١٠٠ كجم نيتروجين/فدان أعلى القيم لمحصول الحبوب والقش والمحصول البيولوجي/فدان عندما كانت نباتات الذرة الرفيعة عند الكثافة النباتية المرتفعة (٣٥٠٠٠ نبات/فدان).