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Improving yield and water productivity of maize grown under deficit-irrigated in dry area conditions

Mohamed H. Abd el-wahed[1], Ayman EL Sabagh[2*], Abdelmoneim Zayed[3], Sanussi Ahmed[3], Hirofoumi Saneoka[4], Celaleddin Barutçular[5]

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ABSTRACT

Scarcity of water is the most severe constraint for development of maize in arid and semi-arid areas. Based on the actual crop need, the irrigation management has to be improved so that the water supply to the crop can be reduced while still achieving high yield. Therefore, the current study has been organized to evaluate the effects of deficit sprinkler irrigation (DSI) and farmyard manure (FYM) on Grain yield (GY) and crop water productivity (CWP) of corn, a 2-year experiment was conducted in arid region of Libya. The DSI treatments were (I_{100} = 100%, I_{85} = 85% or I_{70} = 70%) of the crop evapotranspiration. FYM treatments were (0, 10 ton ha^{-1}) spread either on the soil surface, incorporated with surface or subsurface layer (FYM_{10s}, FYM_{10m} or FYM_{10ss}, respectively) and 20 ton ha^{-1} spread as before (FYM_{20s}, FYM_{20m} or FYM_{20ss}, respectively). Results indicated that the highest values of grain yield (GY) were obtained from I_{100} treatment, while the lowest were observed in I_{70}. FYM_{20ss} enhanced GY than other FYM treatments in both seasons. The highest GY and CWP were recorded with I_{100} and received FYM_{20ss}. It could be considered as a suitable under arid environmental conditions and similar regions, the treatment ($I_{100} \times FYM_{20ss}$) is the most suitable for producing high GY and CWP. Under limited irrigation water, application of ($I_{85} \times FYM_{20ss}$) treatment was found to be favorable to save 15% of the applied irrigation water, at the time in which produced the same GY.

INTRODUCTION

Maize is an important cereal crop grown all over the world (Farhad et al. 2009). Maize had its origin in a semi-arid area but it is not a reliable crop for growing under dry land conditions, with limited or erratic rainfall (Arnon 1972). Maize is apparently more drought resistant in the early stages of growth than when fully developed. Extreme water stress at different stages of crop development has been reported to reduce the yield significantly (Dhillon et al. 1995). Drought is one of the major threats affecting maize production in tropical and subtropical regions or globally.

Drought stress is considered one of the most common factors of limiting plant growth in arid and semiarid regions (Turhan and Baser 2004).Drought stress is one of the most important environ-mental factors in reduction of growth, development and production of plants (Jajarmi 2009). According to Hayat and Ali (2004), Moisture stress is a limiting factor for crop growth in arid and semi-arid regions due to low and uncertainty precipitation.

To cope with the water shortage, it is necessary to adopt water saving agriculture countermeasures as efficient use of irrigation water is which becoming increasingly important. Irrigation scheduling for crops, using advanced irrigation methods (sprinkler and drip) and improved water management practices are very important to water saving (Zaman et al. 2001). Deficit irrigation provides means of reducing water

1- Soil and Water Dept. (Agric. Eng.) Fac. of Agric., Fayoum Univ. Egypt,
2- Agronomy Departments, Faculty of Agriculture, Kafrelsheikh University, Egypt
3- Soils and Water Department, Faculty of Agriculture, Sebha University, Libya
4- Plant nutritional physiology, Graduate School of Biosphere Science, Hiroshima University, Japan
5-Department of Field Crops, Faculty of Agriculture, Cukurova University, Turkey
*Email: aymanelsabagh@gmail.com

consumption while minimizing adverse effects on yield (Zhang et al. 2004).

Using sprinkler systems with its easier operation and automation, have the capacity to attain highly uniform and efficient irrigation results in water saving and farm profitability. This is a major issue for the present and future of irrigable lands in arid and semi-arid regions, where great deal of irrigating water is required (Tarjuelo et al. 1999).

Among the water management practices for increasing water use efficiency, mulching was considered (Khurshid et al. 2006). Mulching is an efficient way to reduce evaporation, improve WUE (Hartkamp et al. 2004) and maintain soil under stable temperature (Kar and Kumar 2007).

The application of organic mulches as a soil cover is effective in improving the quality of soil and increasing crop yield, especially in organic farming (Sinkevičienė et al. 2009). Mulches increase the yield and water use efficiency to a great extent by augmenting the water status in the root zone profile (Mukherjee et al. 2010). Allen et al. (1998) reported that the specific yield response factor (Ky) is a factor that describes the reduction in relative yield according to the deficit in crop evapotranspiration caused by soil water shortage. The present work aimed to investigate the efficiency of deficit sprinkler irrigation and adding FYM on corn yield, yield components and crop water productivity under Sebha region's conditions.

MATERIALS AND METHODS

A field experiment was conducted at the experimental farm, Agricultural Research Center, Sebha, Libya, during the both successive summer seasons of 2009 and 2010. Field trial is located at an altitude of 432 m above sea level and co-ordinates between latitude: 27° 01' N and longitude: 14° 26' E in Sebha. The soil at the experimental site is sandy soil (93.9 % sand, 4.0 % silt and 2.1 % Clay). Some physical properties relevant to irrigation are given in (Table 1). The irrigation system was designed as a solid sprinkler irrigation system. The manifold was posited in the center of the field. It has three pairs of sprinkler laterals. Each pair has a control valve for on and off. The sprinkler laterals is spaced 14 m apart and each lateral has four rotating sprinklers spaced 12 m apart. Sprinkler discharge was 1.5 $m^3 h^{-1}$ at 3 bar nozzle pressure. The crop was irrigated two days intervals by different amount of irrigation water (AIW) from emergence sowing to physiological maturity.

Three treatments of amount irrigation of water (AIW), were I_{100}: 100% of ETc (full irrigation) and two deficit irrigation were I_{85}: 85% and I_{70}: 70% of the ET_c. The daily ET_o was computed according to the equation of FAO-PM (1) (Allen et al. 1998) as follows:

$$ET_o = \frac{0.408\ \Delta\left(R_n - G\right) + \gamma\ \frac{900}{T_{\text{mean}} + 273}\ u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34\ u\right)} \quad \text{............(1)}$$

Where; ET_o: Reference evapotranspiration, mm day^{-1}, Δ: Slope of the saturation vapor pressure curve at air temperature (kPa°C^{-1}), R_n: Net radiation at the crop surface (MJm^{-2} d^{-1}), G: Soil heat flux density (MJm^{-2} d^{-1}), γ: Psychometric constant = (0.665 × 10-3 × P), kPa°C1 (Allen et al. 1998), P is atmospheric pressure (kPa), u_2 : Wind speed at 2 m height (m s^{-1}), e_s: Saturation vapor pressure (kPa), e_a: Actual vapor pressure (kPa), (e_s – e_a): Saturation vapor pressure deficit (kPa), T_{mean}: Mean daily air temperature at 2 m height (°C).

The average daily ET_o in Sebha region was estimated using the monthly mean weather data (1994-2005) of Sebha climatological station. The average of daily ET_o in Sebha was 12.75, 12.94, 12.48 and 10.92 ET_o mm day^{-1} at June, July, August and September, respectively. ET_c was estimated using the crop coefficient according to equation (2):

$$ET_c = ET_o \times K_c$$

Where; ET_c: Crop water requirements, mm day^{-1}, K_c : Crop coefficient

The periods of the different crop growth stages were 25, 40, 45, and 30 days for initial, crop development, mid-season and late season stages, respectively and the K_c of initial, mid and end stages were 0.70, 1.20 and 0.35, respectively, according to (Allen et al.1998).

Amount of irrigation water (AIW) applied to each treatment during the irrigation regime was determined by using Eq. (3):

$$AIW = \frac{A\ x\ ET_C\ x\ L_i}{E_a\ x\ 1000} + L_r$$

Table 1. Some physical properties of different soil layers of the experimental soil.

Depth (cm)	Field capacity (%)	Wilting Point (%)	Available water (%)	Bulk density (g cm^{-3})
0-20	11.5	5.6	5.9	1.51
20-40	11.0	5.3	5.6	1.61

Table 2. The farmyard manure treatments (FYM).

FYM treatments	ton ha^{-1}
FYM_0	0 ton ha^{-1}(Control)
FYM_{10s}	10 ton ha^{-1} spread on the soil surface
FYM_{10m}	10 ton ha^{-1} incorporated with surface layer
FYM_{10ss}	10 ton ha^{-1} incorporated with sub surface layer
FYM_{20s}	20 ton ha^{-1} spread on the soil surface
FYM_{20m}	20 ton ha^{-1} incorporated with surface layer
FYM_{20ss}	20 ton ha^{-1} incorporated with sub surface layer

Where: AIW: amount of irrigation water applied (m^3), A: plot area (m^2), ET_c:crop water requirements (mm day^{-1}), L_i: irrigation intervals (day), E_a: application efficiency (%) (E_a = 70%), L_r: leaching requirements (m^3).

AIW were 6820, 5797 and 4774 m^3 ha^{-1} for I_{100}, I_{85} and I_{70}, respectively. Irrigation treatments were started after full emergence, after that each treatment was irrigated according to prescribed irrigation scheduling treatments. (Table 2) demonstrates the FYM treatments and quantities applied. The chemical analysis of FYM is shown in (Table 3).

Plot unit area was (3×3.5) 10.5 m^2 and 100 kg N ha^{-1} as urea form (46% N) was applied after 30 days of sowing. Grain (Giza-2) was manually sowing (on 1 June 2009 and 5 June 2010) in drills 50 cm apart and 30 cm within hills. Plants were thinned to secure one plant per hill three weeks after planting. All other cultural practices were carried out as recommended for corn production in both seasons. After 45 days from sowing a sample of three plants for each sub-plot area were taken for estimate fresh and dry weight of plant as well as leaf area index (LAI).

At harvest; random samples of five guarded plants for each experimental unit were taken in order to record plant height (cm), number of ears $plant^{-1}$, number of rows ear^{-1}, 100-grain weight (g), grain weight ear^{-1} and shelling %. Grain yield (GY) was determined per each experimental unit then converted to GY kg ha^{-1}, after modifying the moisture content to 15%.

Crop water productivity (CWP) kg m^{-3} which defined as water utilization efficiency was calculated according to (Doorenbos and Pruitt 1977) as equation (4):

$$CWP = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Amount of irrigation water (m}^{3}\text{ ha}^{-1})}$$

Yield response factor (K_y) was calculated according to the equation of (Stewart et al.1977) as equation (5):

$$\left(1 - \frac{Y_a}{Y_m}\right) = k_y \left(1 - \frac{ET_a}{ET_m}\right)$$

(A5) Where; Y_a: Actual yield (kg ha^{-1}), Y_m: Maximum yield (kg ha^{-1}), ET_a: Actual crop evapotranspiration (mm), ET_m: Maximum crop evapotranspiration (mm)

Statistics of the experiment was subjected to analysis of variance (ANOVA) procedures using the MSTAT-C Statistical Software Package (Michigan State University, 1983).The experiments were laid out in a complete randomized block design by split plot arrangement with three replications. Three sprinkler irrigation schedule i.e.100, 85 and 70% of ET_c were assisted in main plots, while the FYM treatments were allocated in the sub-plots. Means were compared by using least significant difference (LSD) at 5% level of probability in both seasons (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Growth traits

Data illustrated in (Tables 4) declared the significant influence of amount irrigation of water (AIW), Farmyard manure (FAM) and their interaction on fresh weight $plant^{-1}$, dry weight $plant^{-1}$, leaf area index (LAI) and plant height in both seasons. The maximum values of previous

Table 3. Chemical analysis of farmyard manure (FYM).

Determination	Ratio
Total N %	0.650
Total p%	0.420
Total K%	1.850
O.M. %	25.50
C%	14.80
C/N ratio	22.77

Table 4. Effect of amounts of irrigation water treatments (AIW), farmyard manure (FAM) and their interactions on fresh and dry weight/plant and leaf area index (LAI).

AIW	FYM	Fresh weight, (g $plant^{-1}$)		Dry weight, (g $plant^{-1}$)		LAI	
		2009	2010	2009	2010	2009	2010
I_{100}	FYM_0	320.0	335.0	80.5	85.0	3.2	3.3
	FYM_{10s}	395.0	400.0	90.0	94.6	3.7	3.5
	FYM_{10m}	410.2	415.2	110.5	115.2	3.9	4.0
	FYM_{10ss}	390.2	400.0	92.0	95.2	3.7	3.6
	FYM_{20s}	450.2	480.0	120.0	125.2	4.0	4.1
	FYM_{20m}	490.1	500.0	150.2	160.1	4.3	4.6
	FYM_{20ss}	440.1	448.8	115.2	120.0	4.0	4.2
	Mean	413.7	425.6	108.3	113.6	3.8	3.9
I_{85}	FYM_0	255.0	260.5	70.1	75.0	2.5	2.6
	FYM_{10s}	278.8	285.2	75.6	76.9	2.9	2.9
	FYM_{10m}	300.0	310.2	80.8	82.2	3.1	3.2
	FYM_{10ss}	285.0	290.1	76.1	77.2	2.8	2.9
	FYM_{20s}	310.1	315.0	85.6	89.2	3.5	3.5
	FYM_{20m}	350.2	360.4	100.5	104.2	3.8	3.9
	FYM_{20ss}	315.0	320.0	90.2	91.0	3.4	3.6
	Mean	299.2	305.9	82.7	85.1	3.1	3.2
I_{70}	FYM_0	210.0	215.0	60.1	61.2	2.2	2.3
	FYM_{10s}	225.2	227.5	69.0	70.1	2.5	2.4
	FYM_{10m}	260.0	270.0	72.3	73.0	2.9	3.1
	FYM_{10ss}	230.0	235.0	70.0	71.5	2.4	2.6
	FYM_{20s}	275.0	277.8	75.0	76.0	2.9	3.3
	FYM_{20m}	310.0	315.0	81.2	82.0	3.4	3.6
	FYM_{20ss}	280.0	379.0	74.2	75.6	2.9	3.2
	Mean	255.7	274.2	71.7	72.8	2.7	2.9
Main effect of farmyard manure	FYM_0	261.7	270.2	70.2	73.7	2.6	2.7
	FYM_{10s}	299.7	304.2	78.2	80.5	3.0	2.9
	FYM_{10m}	323.4	331.8	87.9	90.1	3.3	3.4
	FYM_{10ss}	301.7	308.4	79.4	81.3	3.0	3.0
	FYM_{20s}	345.1	357.6	93.5	96.8	3.5	3.6
	FYM_{20m}	383.4	391.8	110.6	115.4	3.8	4.0
	FYM_{20ss}	345.0	382.6	93.2	95.5	3.4	3.7
LSD (0.05) for (AIW)		8.2	9.16	2.0	2.1	0.09	0.12
LSD (0.05) for (FYM)		10.2	12.0	3.0	3.3	0.10	0.15
LSD (0.05) for (AIW× FYM)		17.65	20.76	5.19	5.71	0.17	0.26

AIW, amount of irrigation water; FYM, Farmyard manure; I_{100}, I_{85} and I_{70}: 100, 85and 70% of the crop evapotranspiration.

traits were registered at full irrigation (I_{100}). This is may be due to the sufficiency of available water in

the soil under this level which led to an increased in absorption of water and elements and consequently an increase in the metabolic mechanisms in the plants leading to the production of new organs and led to heavier plants, increased LAI and plant height due to increased cell elongation. The same trend was observed by (Tahir 1983). Here too, the data revealed that the corn plants received 20 ton ha^{-1} incorporated with surface layer (FYM_{20m}) gave the highest values of dry and fresh weight, LAI and plant height. There is significant interaction between AIW and FAM in this respect in both seasons. The maximum values

Table 5. Effect of amount of irrigation water (AIW), farmyard manure (FYM) and their interaction on plant height (cm), number of ear/plant, number of rows/ear and 100-grain weight (g).

AIW	FYM	Plant height (cm)		Ears ($plant^{-1}$)		Grain rows (ear^{-1})		100-grain weight (g)	
		2009	2010	2009	2010	2009	2010	2009	2010
I_{100}	FYM_0	150.0	165.0	1.0	1.0	12.0	13.0	30.0	31.0
	FYM_{10s}	165.0	175.2	1.2	1.0	12.0	12.0	31.2	32.0
	FYM_{10m}	174.0	180.1	1.1	1.0	13.0	12.0	32.2	33.50
	FYM_{10ss}	164.0	175.0	1.3	1.0	12.0	12.0	30.5	31.0
	FYM_{20s}	180.0	190.0	1.0	1.0	12.0	14.0	33.1	34.0
	FYM_{20m}	199.0	205.0	1.1	1.0	14.0	12.0	35.8	36.0
	FYM_{20ss}	184.0	194	1.1	1.2	12.0	12.0	34.0	34.0
	Mean	173.7	183.5	1.1	1.0	12.4	12.4	32.4	33.1
I_{85}	FYM_0	130.1	136.0	1.2	1.1	12.0	12.0	27.0	28.0
	FYM_{10s}	140.5	148.0	1.1	1.0	12.0	1.2.0	29.0	29.5
	FYM_{10m}	150.2	156.5	1.1	1.0	12.0	13.0	29.9	29.8
	FYM_{10ss}	140.0	148.0	1.0	1.0	12.0	14.0	28.6	29.0
	FYM_{20s}	165.0	170.0	1.0	1.0	13.0	12.0	30.1	30.5
	FYM_{20m}	170.5	177.0	1.2	1.2	12.0	12.0	33.2	33.5
	FYM_{20ss}	163.0	168.2	1.0	1.0	12.0	12.0	31.0	31.4
	Mean	151.3	157.7	1.1	1.0	12.1	12.5	29.8	30.2
I_{70}	FYM_0	122.0	125.0	1.0	1.0	12.0	13.0	24.2	25.0
	FYM_{10s}	130.5	140.0	1.0	1.2	12.0	14.0	26.2	26.9
	FYM_{10m}	140.0	145.6	1.0	1.0	12.0	12.0	28.0	28.5
	FYM_{10ss}	130.0	135.6	1.0	1.0	12.0	12.0	26.0	26.4
	FYM_{20s}	150.0	160.0	1.2	1.3	13.0	13.0	27.2	27.8
	FYM_{20m}	165.0	175.0	1.0	1.1	12.0	12.0	30.1	30.5
	FYM_{20ss}	156.0	158.2	1.1	1.0	12.0	14.0	27.0	27.5
	Mean	141.9	148.5	1.0	1.1	12.1	12.9	27.0	27.5
Main effect of farmyard manure	FYM_0	134.0	142.0	1.1	1.0	12.0	12.7	27.1	28.0
	FYM_{10s}	145.3	154.4	1.1	1.1	12.0	13.0	28.8	29.5
	FYM_{10m}	154.7	160.7	1.1	1.0	12.3	12.3	30.0	30.6
	FYM_{10ss}	144.7	152.9	1.1	1.0	12.0	12.7	28.4	28.8
	FYM_{20s}	165.0	173.3	1.1	1.1	12.7	13.0	30.1	30.8
	FYM_{20m}	178.2	185.7	1.1	1.1	12.7	12.0	33.0	33.3
	FYM_{20ss}	167.7	173.5	1.1	1.1	12.0	12.7	30.7	31.0
LSD (0.05) for (AIW)		1.94	2.00	NS	NS	NS	NS	0.70	0.73
LSD (0.05) for (FYM)		2.0	2.21	NS	NS	NS	NS	0.80	0.85
LSD (0.05) for (AIW× FYM)		3.46	3.82	NS	NS	NS	NS	1.38	1.47

AIW, amount of irrigation water; FYM, Farmyard manure; I_{100}, I_{85} and I_{70}: 100, 85and 70% of the crop evapotranspiration.

of mentioned traits were obtained from corn plants irrigated by I_{100} and received FYM_{20m}.

Corn yield and yield components

Data in (Tables 5 and 6) showed that the 100-grain weight, shelling, grain weight and grain yield were positively affected by the AIW, FYM and their interactions while number of ears per plant and number of rows per ear were not significantly affected.

The maximum values were obtained when the plants were irrigated with the full irrigation (I_{100}), while the minimum values were recorded for the deficit irrigation treatment (I_{70}). As average, the maximum values of grain yield (7004.9 and 7112.1kg ha^{-1}) were obtained when the plants were irrigated with the highest AIW (I_{100}), while the

Table 6 Effect of amount of irrigation water (AIW), farm yard manure (FAM) and their interaction on shelling (%), grain weight ear $^{-1}$, grain yield and CWP.

AIW	FYM	Shelling, %		Grain weight (g ear^{-1})		Grain yield (kg ha^{-1})		CWP (kg m^{3})	
		2009	2010	2009	2010	2009	2010	2009	2010
I_{100}	FYM_0	60.5	61.0	80.0	85.2	5115	5183	0.75	0.76
	FYM_{10s}	63.0	64.0	90.5	96.0	5933	6070	0.87	0.89
	FYM_{10m}	65.6	65.6	100.5	105.2	6274	6411	0.92	0.94
	FYM_{10ss}	62.5	63.0	91.0	93.4	7434	7638	1.09	1.12
	FYM_{20s}	70.5	72.0	120.0	122.2	7706	7775	1.13	1.14
	FYM_{20m}	75.0	74.9	140.0	142.0	8047	8047	1.18	1.18
	FYM_{20ss}	71.0	72.0	118.0	120.5	8525	8661	1.25	1.27
	mean	66.9	67.5	105.7	109.2	7005	7112	1.03	1.04
I_{85}	FYM_0	55.5	56.5	65.5	66.5	3884	4000	0.67	0.69
	FYM_{10s}	58.6	59.0	70.1	71.5	4290	4348	0.74	0.75
	FYM_{10m}	60.5	61.0	77.8	79.0	4753	4869	0.82	0.84
	FYM_{10ss}	59.0	61.5	70.5	70.5	5159	5333	0.89	0.92
	FYM_{20s}	65.0	66.8	85.4	86.0	5449	5565	0.94	0.96
	FYM_{20m}	70.5	72.0	98.6	100.0	6434	6492	1.11	1.12
	FYM_{20ss}	68.2	69.1	86.5	87.0	6898	7188	1.19	1.24
	mean	62.5	63.7	79.2	80.1	5267	5399	0.91	0.93
I_{70}	FYM_0	50.1	52.2	55.6	57.2	2864	3055	0.60	0.64
	FYM_{10s}	53.5	55.2	60.1	63.0	3485	3533	0.73	0.74
	FYM_{10m}	54.8	56.2	65.0	67.8	4106	4249	0.86	0.89
	FYM_{10ss}	52.2	54.8	61.0	63.0	4488	4488	0.94	0.94
	FYM_{20s}	56.8	57.5	70.2	74.0	4774	5013	1.00	1.05
	FYM_{20m}	65.4	66.9	80.1	85.4	5108	5251	1.07	1.10
	FYM_{20ss}	58.5	60.0	72.0	74.0	5251	5395	1.10	1.13
	mean	55.9	57.5	66.3	69.2	4297	4426	0.90	0.93
Main effect of farmyard manure	FYM_0	55.4	56.6	67.0	69.6	3954	4079	0.67	0.70
	FYM_{10s}	58.4	59.4	73.6	76.8	4569	4650	0.78	0.79
	FYM_{10m}	60.3	60.9	81.1	84.0	5044	5176	0.87	0.89
	FYM_{10ss}	57.9	59.8	74.2	75.6	5693	5820	0.97	0.99
	FYM_{20s}	64.1	65.4	91.9	94.1	5976	6117	1.02	1.05
	FYM_{20m}	70.3	71.3	106.2	109.1	6530	6597	1.12	1.13
	FYM_{20ss}	65.9	67.0	92.2	93.8	6891	7081	1.18	1.21
LSD $_{0.05}$ for (AIW)		0.6	0.8	2.1	2.4	188	196	0.09	0.10
LSD $_{0.05}$ for (FYM)		1.1	1.5	2.5	2.7	186	201	0.11	0.12
LSD $_{0.05}$ for (AIW×FYM)		1.9	5.6	4.3	4.7	321	348	0.19	0.20

AIW, amount of irrigation water; FYM, Farmyard manure; I_{100}, I_{85} and I_{70}: 100, 85and 70% of the crop evapotranspiration.

minimum values of grain yield (4296.5 and 4426.1 kg ha^{-1}) were recorded for the lowest one (I_{70}) (Fig.

1). It is clear that the average grain yield of corn crop was increased with increasing AIW (Mahfouz and Abd El-Wahed 2008). Moreover, the deficit irrigation, 15 %(I85) and 30% (I_{70}) from AIW were reduced the grain yield by 24.8% and 38.7% in first season and 24.1% and 37.8 % in the second season respectively. The deficit water irrigations were reduced grain yield by the reduction in the yield components in this experiment. Tahir (1983) indicated that, in arid and semi-arid regions very often moisture stress is the limiting factor for crop growth and yield production. The shortage in grain yield of many crops under the lower AIW may be due to several factors; reduced soil water content that have been shown to delay rooting (Bathke et al. 1992) or with a concomitant reduction in leaf area, root system and shoot dry weight and low photosynthesis rate (Masle and Passiour 1987).

Regarding, Farm yard manure (FYM) treatments, (Table 6) showed that the grain yield was significantly affected by the different rates and methods of FYM application. The values of grain yield were higher for FYM_{20ss} treatment than other FYM treatments. The average grain yield values of FYM_{20SS} were increased by 74.3, 50.8, 36.6, 21.0, 15.3 and 5.5 % than those for FYM_0, FYM_{10s}, FYM_{10m}, FYM_{10ss}, FYM_{20s} and FYM_{20m} in 2009 seasons, respectively.While the corresponding values in 2010 season were 73.6, 52.3, 36.8, 21.7, 15.8 and 7.3 % in the same order. This is to be expected since the same FMY treatment produced the highest values of GY. The obtained results are found to be in agreement with those obtained by

(Abou El-Magd et al. 2008; Abd El-Wahed 2009; Ofosu-Amin and Leitch 2009; Ahmed et al. 2011; Abd El-Wahed and Ali 2013). This is may be due to the roles of farmyard manure in improving soil physical properties as well as increasing soil water holding capacity that encourage better root growth and nutrient absorption (Abou El-Magd et al. 2008). Also, Saleh et al. (2003) revealed that organic manure enhanced the availability of certain elements and their supply to onion plants during the growth period. Also, these results stood in agreement with those obtained by (Ofosu-Amin and Leitch 2009). The interaction between AIW and FYM application had a significant effect on grain yield in both seasons. The highest grain yield (8524.8 and 8661.1 kg ha^{-1}) was recorded for plants irrigated with highest level of AIW (I_{100}) and received FYM_{20ss}. In contrast, the lowest GY (2864.3 and 3055.3 kg ha^{-1}) was obtained from plants irrigated with lowest level of AIW (I_{70}) and FYM_0 in both seasons, respectively.

Crop water productivity (CWP):

Exhibited data in (Table 6) focused that CWP was significantly affected by different AIW and FYM and their interactions. The average of CWP values were 1.03, 0.91 and 0.90 kg grain m^{-3} water for I_{100}, I_{85} and I_{70} treatments in first season, respectively. While the corresponding values in second season were 1.04, 0.93 and 0.93 kg grain per m^3 water in the same order. The superiority of full irrigation treatment (I_{100}) in this respect was explained by the high GY produced from this treatment. The obtained result is full agreements with obtained by (Abd El-Wahed and Ali 2013). They reported that the highest yield obtained from I_{100} treatment which compensated the highest amount of water used and gave the highest return from the water unit in both seasons.

The average CWP values of FYM_{20ss} were increased by 79.7, 65.3, 47.6, 34.8, 29.2 and 10.7 % over FYM_0, FYM_{10s}, FYM_{10m}, FYM_{10ss}, FYM_{20s}, and FYM_{20m} in 2009 seasons, respectively. While the corresponding values in 2010 season were 77.6, 60.8, 45.1, 33.7, 26.6 and 7.2 % in the same order. This is to be logic since the same treatment gained the highest GY and consequently CWP.

The interaction between the tested variables (AIW and FYM treatments) had a significant effect on CWP (Table 6). The highest CWP values (1.25 and 1.27 kg grain m^{-3} water) were obtained from plants irrigated with the full irrigation (I_{100}) and received FYM_{20ss} in both seasons, respectively. Meanwhile, the lowest CWP (0.60 and 0.64 kg grain m^{-3}) were recorded when plants were irrigated with (I_{70}) and received FYM_0 in both seasons, respectively.

Yield response factor (Ky)

Table 7, shows the relationship between the reductions in relative yield according to the reduction in AIW under FYM application. The [1-(Y_a/Y_m)] value was increased with increasing [1-(ET_a/ET_m)], where its values for full irrigation (I_{100}) were always higher than those of deficit irrigation (I_{85} and I_{70}).

The Ky values were greater than unity, indicating that corn crop, generally, is very sensitive to water stress. This result is in full agreement with those reported by (Doorenboss and Kassam 1979; Abd EL-Wahed 2009; Ahmed et al. 2011; Smith and Steduto 2012). In this concern, Kirda (2002) reported that a value of Ky greater than unity indicates that the expected relative yield decrement for a given crop evapotranspiration deficit is proportionally greater than the relative decrease in crop evapotranspiration. The rates of water saving were 15 and 30 %, while the rates of the decrease in relative yield were 24.1 and 44.0 % in first season, 22.8 and 41.1% in second season under FYM_0, respectively. While under FYM_{10s} were 27.7 and 41.3% in first season, 28.4 and 41.8% in second season, respectively. Under FYM_{10m} were 24.2 and 34.6% in first season, 24.0 and 33.7% in second season, 30.6 and 39.6% in first season, 30.2 and 41.2% in second season

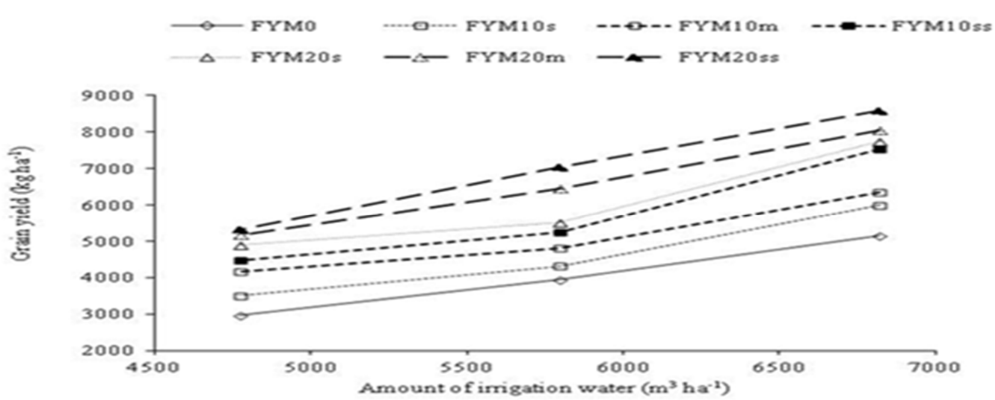

Figure 1. The relationship between amount of irrigation water and grain yield at different FYM treatments.

Table 7. The combined relationship between the reductions in relative yield according to the reduction in AIW under FYM application.

Treat ment	AIW, (m^3 ha^{-1})	G y (kg ha^{-1})		Y_a/Y_m		ET_a/ET_m	1- Y_a/Y_m		ET_a/ET_m	K_y	
		2009	2010	2009	2010		2009	2010		2009	2010
FYM_0											
I_{100}	6819	5114	5183	1.00	1.00	1.00	0.000	0.000	0.00	0.00	0.00
I_{85}	5796	3883	3999	0.76	0.77	0.85	0.241	0.228	0.15	1.60	1.52
I_{70}	4773	2864	3055	0.56	0.59	0.70	0.440	0.411	0.30	1.47	1.37
FYM_{10s}											
I_{100}	6819	5933	6069	1.00	1.00	1.00	0.000	0.000	0.00	0.00	0.00
I_{85}	5796	4289	4347	0.72	0.72	0.85	0.277	0.284	0.15	1.85	1.89
I_{70}	4773	3484	3532	0.59	0.58	0.70	0.413	0.418	0.30	1.38	1.39
FYM_{10m}											
I_{100}	6819	6274	6410	1.00	1.00	1.00	0.000	0.000	0.00	0.00	0.00
I_{85}	5796	4753	4869	0.76	0.76	0.85	0.242	0.240	0.15	1.62	1.60
I_{70}	4773	4105	4248	0.65	0.66	0.70	0.346	0.337	0.30	1.15	1.12
FYM_{10ss}											
I_{100}	6819	7433	7638	1.00	1.00	1.00	0.000	0.000	0.00	0.00	0.00
I_{85}	5796	5159	5333	0.69	0.70	0.85	0.306	0.302	0.15	2.04	2.01
I_{70}	4773	4487	4487	0.60	0.59	0.70	0.396	0.412	0.30	1.32	1.38
FYM_{20s}											
I_{100}	6819	7706	7774	1.00	1.00	1.00	0.000	0.000	0.00	0.00	0.00
I_{85}	5796	5449	5564	0.71	0.72	0.85	0.293	0.284	0.15	1.95	1.89
I_{70}	4773	4773	5012	0.62	0.64	0.70	0.381	0.355	0.30	1.27	1.18
FYM_{20m}											
I_{100}	6819	8047	8047	1.00	1.00	1.00	0.000	0.000	0.00	0.00	0.00
I_{85}	5796	6434	6492	0.80	0.81	0.85	0.200	0.193	0.15	1.34	1.29
I_{70}	4773	5108	5251	0.63	0.65	0.70	0.365	0.347	0.30	1.22	1.16
FYM_{20ss}											
I_{100}	6819	8524	8661	1.00	1.00	1.00	0.000	0.000	0.00	0.00	0.00
I_{85}	5796	6898	7188	0.81	0.83	0.85	0.191	0.170	0.15	1.27	1.13
I_{70}	4773	5251	5394	0.62	0.62	0.70	0.384	0.377	0.30	1.28	1.26

under FYM_{10ss}, respectively. While under FYM_{20s} were 29.3 and 38.1% in first season, and 28.4 and 35.5 in second season, 20.0 and 36.5 % in first season, 19.3 and 34.7 % in second season under FYM_{20m}. Finally, under FYM_{20ss} were 19.1 and 38.4% in first season, 17.0 and 37.7 in second one, respectively.

CONCLUSION

The results obtained in this study demonstrate that the highest values of GY and CWP were obtained from full irrigation treatment (I_{100}) while the lowest ones were observed in high deficit irrigation treatment (I_{70}). The GY and CWP were significantly and positively affected by FYM. The highest GY and CWP were recorded for plants receiving FYM_{20ss} in the two growing seasons. The highest GY and CWP values were obtained from plants irrigated with the full irrigation (I_{100}) and received FYM_{20ss} in both seasons. Meanwhile, the lowest CWP were recorded when plants were irrigated with deficit irrigation treatment (I_{70}) and received FYM0 in both seasons. Under Sebha environmental conditions and similar arid regions, the authors recommend applying the cultivation of corn plants under the treatment ($I_{100} \times FYM_{20ss}$) as it is the most suitable for producing high grain yield. Under limited irrigation water in the arid conditions; application of each amount of FYM has improved CWP and helps to reduced irrigation water till to 15%. Consequently, this implies that can be used as a strategy to improve water productivity (WP) and grain yield of maize in under dry area conditions.

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