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Effect of Drip Irrigation Levels and Emitters Depth on Okra (*Abelmoschus esculentus*) Growth

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Abstract: Okra *Abelmoschus esculentus* (Climson Spineless CV.) growth, rooting, yield and water use efficiency were evaluated in a field trial, where four irrigation rates at 60 (T_1), 80 (T_2), 100 (T_3) and 120% (T_4) of the estimated evapotranspiration (ETo) and four drip irrigation emitters depth: surface 0.0 m depth (D_0), sub-surface at 0.15 m depth (D_1), at 0.25 m depth (D_2) and at 0.35 m depth (D_3) were imposed following a split-plot in a randomized complete block experimental design with three replications in 2005 and 2006 seasons. Vegetative growth characters (plant height, number of leaves, shoot fresh and dry weight), rooting (weight, length, width and root/shoot ratio), early and total yields were measured. Marketable Total Yield (MTY) increased significantly with the increase of irrigation level in both seasons. MTY for T_3 treatments were 14.32 t ha^{-1} in 2005 and 10.29 t ha^{-1} in 2006 and for D_1 treatments were 10.8 t ha^{-1} in 2005 and 9.75 t ha^{-1} in 2006 season. The Crop Water Use Efficiency (CWUE) ranged from 1.45-2.93 kg m^{-3} and 1.29-2.43 kg m^{-3} in 2005 and 2006, respectively. MTY increased significantly as emitter depth increases from surface to 0.35 m in both seasons. Crop Water Production Function (CWPF) was done on the results. It reflects the beneficial of applied water in increasing yield. The CWPF was represented by quadratic polynomial equations.

Key words: Surface drip irrigation, subsurface drip irrigation, emitter depth, irrigation water salinity, crop water use efficiency, crop water production function

INTRODUCTION

Okra (*Abelmoschus esculentus* L.) is an important vegetable crop in Kingdom of Saudi Arabia, for its economical and nutritional values. The total production area of okra in Saudi Arabia was 4343 ha in 2005, producing more than 51848 t (Ministry of Agriculture, 2005). So it is considered one of the main vegetable crops grown in summer season in the Kingdom. The major commercial cultivar of okra is Climson Spineless. Okra plant require warm temperatures and unable to tolerate low temperature for long time or tolerate any threat of frosts. The optimum temperatures are in the range of 21-30°C, with minimum temperatures of 18°C and maximum of 35°C. Okra is a high water crop use despite having considerable drought resistance. The plant forms a deeply penetrating tap root with dense shallow feeder roots reaching out in all directions in the upper 0.45 m of soil.

Water is one of the most important inputs essential for crop production. In Saudi Arabia, water is precious commodity, available in limited quantity and mostly obtained from ground water which the agricultural sector consumes more than 85% of the total annual water consumption. The sustainable use of water resources is a priority for agricultural development in Saudi Arabia. Therefore, practices that increase water use efficiency and reduce excessive amount of water applied to the field are important in water management. The use of drip irrigation alone or in combination with mulch can increase the okra and tomato crop yield significantly over furrow irrigation (Tiwari *et al*., 1998).

Several investigators showed that the use of sub-drip irrigation system produced the same or more yield for several horticultural crops compared to surface drip irrigation (Hutmacher *et al*., 1985; Phene *et al*., 1987; Camp *et al*., 1993; Davis *et al*., 1985; Ayars *et al*., 1999; Machado *et al*., 2003). This could be attributed to factors affecting evaporation from top soil (Camp, 1998) such as burying of irrigation pipe in sub-surface irrigation systems. Phene (1991) and Phene *et al*. (1992) reported that sub-irrigation system reduce the amount of irrigation water, especially in the early development stage of the plants. Al-Omran *et al*. (2005) reported a significant

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differences between sub-surface and surface drip irrigation in the growth and yield of squash, indicating that the most important advantage of subsurface irrigation was decreasing the accumulation of salts in the root distribution zone and increasing the moisture level as the roots of the plants were in active status. Oliveira *et al.* (1996) reported that the roots growth around the emitters, under subsurface irrigation, increase the water use efficiency.

Sub-surface drip irrigation at the depth of 0.45 m contributed to 10-28% increase in the early and marketable yield of cantaloupe (Ayars *et al.*, 1999). In a three years study on broad bean, Bryla *et al.* (2003) showed that the sub-surface irrigation had improved the yield and increased water use efficiency at depths of 0.30 and 0.40 m, but decreased at the depth of 0.60 m. Khalilian *et al.* (2000) found a significant increase in the yield of cotton at the depth of 0.40 m compared to 0.20 and 0.30 m. Recently, Machado and Oliveira (2003) studied the effect of three emitters depth (0.0, 0.30 and 0.40 m) in sub-irrigation system on the root distribution of tomato plants, they found that most of the root system concentrated in the upper 0.40 m of the soil.

The relationship between the marketable yield or yield and irrigation water or ET has been reported for non-saline and saline irrigation water by many researchers (Simsek *et al.*, 2005; Kipkorir *et al.*, 2002; Cuenca, 1987; Dehghanisanij *et al.*, 2006). The form of the regression equations in most of these studies were polynomial with applied water or linear relationship with ET.

The aim of this study was to determine the effect of drip irrigation levels, applied at different ratio of estimated ETo and emitter's depth on growth and yield characteristics of okra grown in the fields.

MATERIALS AND METHODS

The field experiments were carried out at the Agricultural Experimental Station Farm, College of Food and Agricultural Sciences, King Saud University, located at Dierab (24°25' N, 46°34' E), 40 km Southwest of Riyadh, during 2005 and 2006 seasons. Selected properties of the soil and irrigation water were determined by the standard procedure (Page *et al.*, 1982) and are shown in Table 1. Climson Spineless cultivar of okra was directly seeded in ridges with 3 seeds per hill. The seedlings were thinned into one strong per hill after emergence. The experimental layout was split plot, in randomized complete block design with three replications. A field plot 60 m long × 12 m wide was divided into four equal plots (7×4 m^2) with a buffer strip of 2 m left in the middle. The experimental unit consisted of 3 ridge, 3 m long and 1.0 m wide, spaced 0.5 m, giving 21 plants per plot of 7 m^2 total area. Four irrigation levels (T_1 = 60, T_2 = 80, T_3 = 100 and T_4 = 120% of ETo). Whereas, irrigation drip line emitters depth were randomly arranged as sub-plots, as 0.0 m as surface drip line irrigation, 0.15, 0.25 and 0.35 m as sub-surface drip line depth. At the first three weeks, surface drip irrigation was used for all experiment till the plants stand strongly and homogeneously, to be sure that all plants obtained the same amount of water without any difference, after that, the application of treatments started. The amount of water applied for each irrigation level was measured by using an automatic counter as m^3. A sample of three random plants from each plot was taken after the completion of vegetative growth, for measuring the vegetative growth characters, as plant height (m), number of leaves, fresh weight and dry weight percentage of vegetative growth. At harvest, to evaluate yield, all pods

Table 1: Some physical and chemical characteristics of the soil and irrigation water

	Soil depth (cm)		
Soil parameters	0-15	15-60	60-90
SP (%)	18.30	16.30	20.1
EC_e (dS m^{-1})	1.65	3.20	2.7
pH (soil paste)	8.50	8.00	7.8
SAR	0.36	0.53	0.2
$CaCO_3$ (g kg^{-1})	269.00	353.00	336.0
Clay (%)	8.00	7.00	6.5
Silt (%)	0.00	3.00	2.5
Sand (%)	92.00	90.00	91.0
Texture	Sandy	Sandy	Sandy

Irrigation water

		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$	SAR
pH	EC (dS m^{-1})	meq L^{-1}								
7.45	4.35	17.30	16.92	22.96	0.50	Tr.	4.0	21.5	32.5	5.6

of plants grown in each treatment were hand harvested, when it reached 3-5 cm. The early yield was recorded as 25% of the number and weight of first harvest. The total yield of pods (number and weight) of all harvests, for each treatment was calculated. At the end of experiments, samples of three entire plants were taken carefully without injuring root system, by digging around two plants to measure: root length, root weight and the root/shoot ratio.

All cultural practices, including fertigation and pest control were carried out as used in commercial production of okra.

CWPF reflects the benefits of applied water in production of dry matter or yield. It was relationship between the quantity of applied water and the yield or production of crop. The quadratic polynomial function of Helweg (1991) and can be used for economical analysis. It has the form:

$$Y_a = b_0+b_1*X+b_2*X^2 \quad (1)$$

Where:

Y_a = Crop production or yield (t ha^{-1})
X = Applied irrigation water (m^3 ha^{-1})
b_0, b_1 and b_2 = Fitting coefficients

Maximum applied water (X_{max}) was calculated by differentiating the CWPF (Eq. 1) and equating it to zero, Then the maximum predicted yield (Y_{max}) can be calculated by substituting the X_{max} in the Eq. 1 (Abdel-Nasser, 2001, 2005):

$$\frac{\partial Y}{\partial X} = b_1 + 2*b_2*X = 0$$
$$X_{max} = \frac{-b_1}{2*b_2} \quad (2)$$
$$Y_{max} = b_0 + b_1*X_{max} + b_2*(X_{max})^2$$

Analysis of variance procedures were performed to test various treatments and its interaction, using SAS system (SAS, 1996). The Least Significant Difference (LSD) test used at ($p \leq 0.05$) to compare the treatment means.

RESULTS AND DISCUSSION

Results of analysis of variance for the okra yield, root growth and water use efficiency as affected by irrigation level and emitter depth showed that, there were significant effects of irrigation level and emitter depth on the vegetative and root growth and yield of okra, during the two summer growing seasons. However, some significant interaction effects were also found. These effects are discussed separately as follows:

Effect of irrigation level

Vegetative growth: Results showed in Table 2 show the effects of irrigation rates on the vegetative growth of Okra. Higher amount of irrigation water significantly increase the plant height, leaf number and total fresh weight. While, the shoot dry weight percentage was significantly decreased with increasing irrigation rate. This result could be attributed to the reduction of applied water which may affect the physiological processes and tended to expose the plants to water stress which will be reflected to the water absorption and transmission to the different parts of the plant.

Root growth: The results in Table 3 showed clearly that the root weight of okra plants significantly increased with the increase of water level (T_1 to T_4) during the two seasons. Whereas, the results showed inconsistent root /shoot ratio with increasing the irrigation levels. This result was similar to those obtained by Al-Damry (2006) in his study on tomato in Saudi Arabia.

Yield components: Table 4 showed that increasing irrigation level from 60 to 120% of ETo significantly increased the early and total yield. The early and total yields were increased as the irrigation level increased. The highest values of early and total yields were 2.77, 3.28 and 15.20, 11.18 t ha^{-1} during 2005 and 2006 seasons, respectively. These results in agreement with those reported by Al-Omran *et al.* (2005) who indicated that yield of squash was significantly increased with increasing irrigation rate. Tollefson (1985) reported that

Table 2: Effect of irrigation rates on vegetative growth characters of okra during 2005 and 2006 seasons

	Plant height (cm)		No. of leaves		Shoot fresh weight (kg)		Shoot dry weight (%)	
Irrigation rates	2005	2006	2005	2006	2005	2006	2005	2006
T_1	37.79A	44.75C	33.83B	36.67B	3.018C	3.09C	23.93A	29.57C
T_2	39.17A	43.42C	33.67B	34.25B	3.319C	3.48B	15.96B	20.38BC
T_3	39.58A	47.17B	41.92A	42.00A	3.929B	3.56B	18.33B	24.51AB
T_4	38.42A	49.67A	40.92A	41.00A	4.677A	4.26A	19.63AB	26.40A

*Values followed by the same alphabetical letter(s) are not significantly different; $p \leq 0.05$ revised LSD test cotton yield was significantly increased with increasing irrigation rates as result of better vegetative growth.

Total water use: The yield production in any crop depends on its capability to utilize existing resources. The most significant inputs for the crop production in Saudi Arabia is the effective use of irrigation water. This effectiveness use of water is measured by the ratio of marketable total yield and water consumed. Total water applied to treatment (T_1), (T_2), (T_3) and (T_4) were 377, 582, 847 and 1064 mm for 2005 season and were 322, 502, 769 and 945 mm for the 2006 season. A polynomial relationship was determined between (MTY) and (AW) for both season (Fig. 1) using Crop water production function (CWPF) equation to predict maximum yield for both seasons. The predicted maximum yield was 17.77 and 14.2 t ha^{-1} for both season, respectively. The actual yield obtained form the experiment was 15.2 and 11.18 t ha^{-1} for the first and second season, respectively. The corresponding calculated applied water was 22500 and 18333.33 m^3 ha^{-1}, respectively.

Irrigation levels significantly affected the Crop Water Use Efficiency (CWUE) of okra (Table 4). The values of the CWUE were decreased the increasing the irrigation levels in both seasons. The highest values were obtained with T_1. The values of CWUE for T_1 were 2.94 and 2.43 kg m^{-3}, for season 2005 and 2006, respectively. The decreasing of CWUE with increasing irrigation level is attributed to the increasing of applied water.

Effect of irrigation system and emitters depth

Vegetative growth: Results in Table 5 showed generally that, subsurface drip irrigation gave a better result than surface irrigation on the vegetative characters (plant height, number of leaves, shoot fresh weight). Shoot dry weight percentage was higher on the surface drip irrigation.

Replacing emitters at the depth of 15 and 25 cm, resulted in significantly higher pant height, number of leaves and shoot fresh weight compared to 35 cm. Whereas, the dry weight percentage of vegetative growth was significantly increased compared to 15 and 25 cm.

Root growth: Result in Table 6 showed that subsurface irrigation significantly increased the root weight, root length and width and root shoot ratio as compared to surface irrigation. Root growth at 35 cm was significantly higher in terms of weight, length and root/shoot ratio compared to other treatments (0, 15 and 25 cm).

Oliveira *et al.* (1996) reported that more than 90% of the root growth concentrated in the upper surface (up to 30 cm) of the soil. This is may be attributed to the good

Table 3: Effect of irrigation level on root growth characters of okra during 2005 and 2006 summer seasons

Irrigation levels	Root weight (g)		Root length (cm)		Root/shoot ratio (%)	
	2005	2006	2005	2006	2005	2006
T_1	77.00B	65.58C	69.58A	71.00A	20.08B	22.30A
T_2	59.67D	57.75B	69.83A	68.17A	24.92A	20.18B
T_3	65.25C	66.25C	68.75A	69.67AB	27.33C	20.57AB
T_4	94.83A	91.83A	58.08B	59.50C	20.50D	22.31A

*Values followed by the same alphabetical letter(s) are not significantly different; p≤0.05 revised LSD test

Table 4: Effect of irrigation level on yield component of okra during 2005 and 2006 seasons

Irrigation levels	Early yield (t ha^{-1})		Total yield (t ha^{-1})		CWUE	
	2005	2006	2005	2006	2005	2006
T_1	1.77B	1.95D	11.07D	7.81D	2.94	2.43
T_2	2.04B	2.31C	12.23C	9.22C	2.12	1.84
T_3	2.96A	2.59B	14.32B	10.29B	1.69	1.34
T_4	2.77A	3.28A	15.20A	11.18A	1.44	1.29

*Values followed by the same alphabetical letter(s) are not significantly different; p≤0.05 revised LSD test

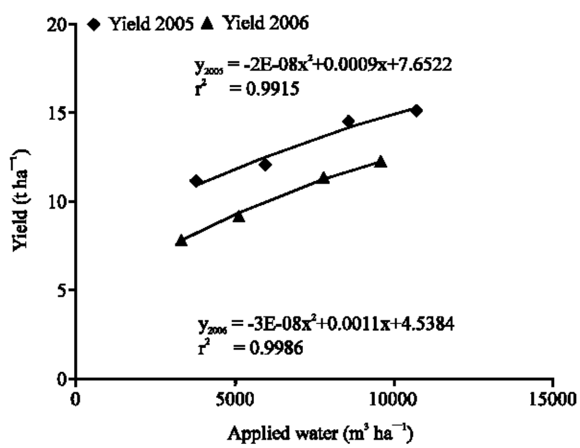

Fig. 1: The relationship between okra yield and applied water under drip irrigation

Table 5: Effect of emitter's depth on vegetative growth of okra during 2005 and 2006 seasons

Emitter depth	Plant height (cm)		No. of leaves		Fresh weight of vegetative		Dry weight of vegetative (%)	
	2005	2006	2005	2006	2005	2006	2005	2006
D_0	36.92C	41.17C	35.17BC	34.67C	3.469B	3.272BC	20.34A	33.26B
D_1	43.30A	51.67A	42.83A	44.42A	4.88A	4.53A	16.38B	26.47A
D_2	43.83A	47.17B	34.25C	34.92C	3.189B	3.076C	21.25A	25.25A
D_3	40.88B	45.17B	37.83B	39.92B	3.408B	3.547B	19.88A	26.79A

*Values followed by the same alphabetical letter(s) are not significantly different; p≤0.05 revised LSD test

Table 6: Effect of emitter's depth on root growth characters of okra during 2005 and 2006 seasons

Emitter depth	Root weight (g) 2005	Root weight (g) 2006	Root length (cm) 2005	Root length (cm) 2006	Root/shoot ratio (%) 2005	Root/shoot ratio (%) 2006
D_0	75.000B	70.000B	73.083B	62.25B	35.83B	17.08B
D_1	69.667C	68.000B	60.833B	62.250	29.33C	23.28A
D_2	72.667B	69.250B	59.417B	71.000A	39.42A	21.83A
D_3	79.417A	74.500A	72.917A	73.080A	38.25A	23.18A

*Values followed by the same alphabetical letter(s) are not significantly different; $p \leq 0.05$ revised LSD test

Table 7: Effect of emitter's depth on yield component of okra during 2005 and 2006 seasons

Emitter depth	Early yield (t ha^{-1}) 2005	Early yield (t ha^{-1}) 2006	Total yield (t ha^{-1}) 2005	Total yield (t ha^{-1}) 2006
D_0	2.14B	14.40B	10.78D	9.15C
D_1	2.38B	15.20B	10.78C	9.74B
D_2	2.41AB	16.75A	12.24B	9.92B
D_3	2.61A	16.92A	14.32A	10.72A

*Values followed by the same alphabetical letter(s) are not significantly different; $p \leq 0.05$ revised LSD test

balance of moisture and aeration in the root zone with increasing the emitters depth which enhanced the growth of root system, compared to surface irrigation which tended to increase of moisture level in the upper surface.

Yield: Table 7 showed that, the subsurface drip irrigation resulted in significantly higher early and total yield of okra, compared to surface drip irrigation, during the two seasons. The emitter's depth of 35 cm gave a significantly higher early and total yield during 2005 and 2006 as compared to 15 and 25 cm depths. These results in agreement with results reported by Sammis (1980), Hutmacher *et al.* (1985), Bar-Yosef *et al.* (1991), Camp *et al.* (1993), El-Gindy and El-Araby (1996) and Al-Omran *et al.* (2005) who indicated that subsurface drip irrigation resulted in higher yield compared to surface drip irrigation. This could be attributed to the factors affecting evaporation from top soil, as the burying of irrigation pipe with sub-irrigation reduces it. Al-Damry (2006) found that tomato yield was higher at the emitter depth of 25 cm. They contributed that to the better balance in the soil moisture, aeration and plant nutrient in the root zone depth.

Interaction effects between the irrigation rates and irrigation systems and emitters depth: The data showed some interaction effects between the irrigation rates and emitters depth on some of the studied parameters. It was clear that the maximum plant height could be obtained when irrigating the plant at 60% of ETo using surface irrigation. While the use of subsurface irrigation at a depth of 15 cm combined with any irrigation rate, significantly decreased the plant height. Total yield was higher when using 120% of ETo with subsurface irrigation at a depth of 25 cm, while the total yield significantly decreased when the plant irrigated at 60% of ETo with subsurface irrigation at a depth of 15 cm. On the other hand, the root weight reached its highest value when irrigated at 120% of ETo combined with subsurface irrigation at a depth of 25 and/or 35 cm and the lowest value with the plant irrigated at 80% of ETo with subsurface drip irrigation at a depth of 35 cm. Root length, was at maximum value the plant irrigated at 80% of ETo with subsurface irrigation at 25 and 35 cm. While the lowest value when the plan irrigated at 120% with surface irrigation. The maximum root/shoot ratio was recorded when applying water at 80% of ETo with subsurface drip irrigation at a depth of 15 and /or 25 cm. While, the lowest root value was recorded when the plant irrigated at 120% of ETo with surface irrigation. Finally, the maximum early yield was obtained when applying water at 100% of ETo with subsurface irrigation at a depth of 15 cm. On the other hand, the lowest yield was recorded when the plant irrigated at 60% of ETo with sub-surface drip irrigation at a depth of 15 cm.

CONCLUSION

Using subsurface irrigation resulted in better growth and yield especially at the depth of 35 cm. The main advantages of subsurface irrigation could related to the reduction of the evaporation from the soil surface and reducing salts accumulation in the root zone which make the plants active and water content was relatively higher.

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