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Response of okra to water stress

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Ö Z E T / A B S T R A C T

Aims: The purpose of this study was to determine sensitivity of okra against water stress, and also examined plant growth, yield components, water consumption and water use efficiency under water stress conditions.
Methods and results: Different water amounts were applied to determine response of okra (Abelmoschus esculentus L. Akköy 41) to water stress in a study conducted in Tokat/Turkey. The irrigation treatments consisted of the applications of 100%, 75% and 50% of depleted water from root zone of okra. The experiment was designed according to randomized block with three replications. Soil moisture along okra growing season was monitored by gravimetric method. Water consumption and fresh fruit production were found 664 mm and 28690 kg ha^{-1}, 596 mm and 24691 kg ha^{-1} and 506 mm and 20554 kg ha^{-1} for I100, I75 and I50 treatments, respectively. Fresh fruit yield and total dry biomass above ground were significantly affected from water stress but fruit numbers and fruit yield per plant, mean fruit weight, dry fruit yield, harvest index, irrigation water use efficiency and water use efficiency were not affected significantly.
Conclusions: Okra was found sensitive against water stress for fresh fruit yield with yield response factor of 1.22 while it was found tolerant for dry fruit yield with yield response factor of 0.71. Dry matter ratio of fruit increased from 15.1% for I100 to 18.0% for I50 treatment. It can be concluded from the results that okra under water stress promoted fruit yield against vegetative growth because of its increasing harvest index.
Significance and impact of the study: When okra grown under full irrigation conditions it should be marked as fresh to obtain higher profits. When okra exposed to water stress it should be marked after drying to prevent profit lost.

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INTRODUCTION

Okra (*Abelmoschus esculentus L.*) is a traditional vegetable crop in many tropical, subtropical, and warmer parts of the temperate region. Okra is classified as a member of *Malvaceae* family and spread out probably from East Africa (Echo, 2003). Martin ve ark. (1981) evaluated 29 morphological characters of 585 okra accessions from all over the world. The material from Turkey had the largest sample size and was represented by 113 accessions (Duzyaman, 2005). Its Turkish name is known as “bamya”. It is not a very common vegetable in most European countries, except in Greece and in some parts of Turkey. It is available round the year with a peak season of summer months. Okra is primarily a southern vegetable garden plant, grown for its immature pods, which are consumed cooked either alone or in combination with other foods. There are some special varieties preferred by processing industries and others that are consumed as dried or fresh in Turkey (Çalışır ve ark., 2005). Okra is one of the important vegetables in human diet with minerals, carbo-hydrates, fats, proteins and vitamins. 100 g edible okra has 0.7 g minerals, 6.4 g carbo-hydrates, 0.2 g fats, 1.9 g proteins, 1.2 g fibers (Gopalan ve ark., 1989, Abd El-Kader ve ark., 2010). Totally 9.64 million tones okra were produced from 2.40 million ha area in 2017. Averaged okra yield of world was 4013.8 kg ha^{-1} (FAO, 2019). The highest okra producer countries of the world are India, Nigeria and Sudan with 6 million tones, 2.06 million tones and 0.297 million tones, respectively (FAO, 2019). In Turkey, 28536 tones okra were produced from 5559 ha area (FAO, 2019) and okra production showed decreasing trend for the last decade.

Different okra yields were reported based on various irrigation systems. Siyal ve ark. (2016) reported okra yields in Pakistan as 13118 kg ha^{-1} for alternate furrow irrigation method, as 14158 kg ha^{-1} for conventional furrow irrigation method and as 9900 kg ha^{-1} for flood irrigation method. In an other experiment, okra yields for different mulching conditions varied between 2.6 and 6.7 t ha^{-1} along a drought year and varied 3.6 and 8.1 t ha^{-1} along a wet year (Adekiya ve ark., 2017). Okra irrigated by drip system produced 17150 kg ha^{-1} pod yield while okra irrigated by flood rrigation method produced 11980 kg ha^{-1} in Sudan (Abubaker ve ark., 2014).

In this study, determining of okra sensitivity to water stress was aimed and water consumption, yield, biomass and water use efficiency of okra were investigated.

MATERIAL and METHODS

An experiment in the research area of Gaziosmanpaşa University in Tokat/Turkey was carried out to evaluate the effects of water stress on growth and yield of okra and to determine yield response factor of okra. The experimental area was at 40°20′1.2″ N and 36°28′24″ E coordinates. Tokat province is in the Middle Black Sea Region of Turkey. Annual precipitation is 430.6 mm of which 30% (132.6 mm) fall between May and September. The warmest months are July and August (24.4 and 24.5°C) and the coldest month is January with 1.9°C average temperature (MGM, 2019). The soil of the experimental area has clay texture with 19 mm/h final infiltration rates (Figure 1). Some soil properties of the area were documented in Table 1. Akköy41 cultivar of okra (*Abelmoschus esculentus* L. Akköy 41) was used for this experiment. Akköy41 belongs to the Sultani group which the most widespread group in Turkey. This group is grown for both fresh consumption and canning (İnan, 1996). Akköy41 cultivar is moderately tolerant to soil salinity with 3.48 dS m^{-1} threshold and 4.2% yield decrease slope (Unlukara ve ark., 2008).

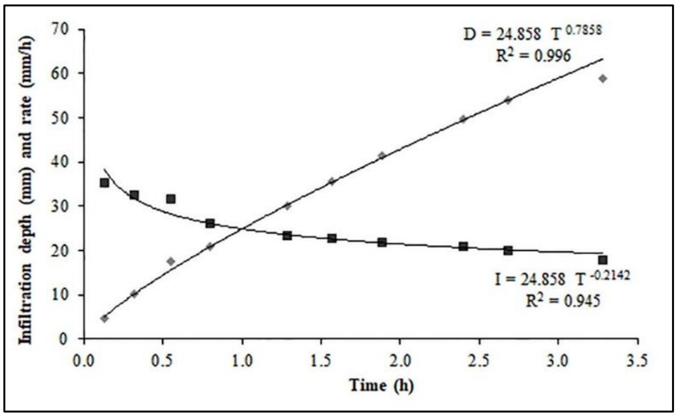


Figure 1. Cumulative infiltration and infiltration rate relationships of the experimental soil

Table 1. Some soil properties of the research area

	Sand (%)	Silt (%)	Clay (%)	ECe (dS m^{-1})	pH	$CaCO_3$ (%)	γ (g cm^{-3})	θ_{fc} (cm^3cm^{-3})	θ_{wp} (cm^3cm^{-3})
0-30	28.1	27.5	44.4	0.89	8.55	13.1	1.29	0.345	0.172
30-60	29.4	28.7	42.0	0.64	8.56	13.0	1.38	0.303	0.150
60-90	27.2	26.3	46.5	0.54	8.59	14.8	1.38	0.301	0.149

Okra was exposed to three irrigation regimes named as full irrigation (I_{100}), slight water stress (I_{75}) and moderate water stress (I_{50}) in 2007. Depleted water by okra from 0.6 m rooting depth was determined by gravimetric soil sampling. Therefore, 100%, 75% and 50% of the depleted water from I_{100}, I_{75} and I_{50} treatments were replenished by irrigation, respectively. The experiment was set up as completely randomized design with three replications per treatment. Each treatment has a 2.5×3.0 plot sizes and 7.5 m^2 plot area. Okra seeds were sown with 0.3 m spaces in rows and 0.5 m spaces between rows. So, each plot had 50 okra plants.

Okra fertilizer needs (N-P-K) were advised as 40-50 kg nitrogen ha^{-1}, 80-90 kg P_2O_5 ha^{-1} and 100-120 kg K_2O ha^{-1} (Vural ve ark., 2000). Therefore, 100 kg P_2O_5 ha^{-1} by using mono ammonium phosphate ($NH_4H_2PO_4$) and 120 kg K_2O ha^{-1} by using potassium nitrate (KNO_3) fertilizers was applied. KNO_3 was divided two equal parts, one part was applied after plant emergence and other part was applied 1 month later. Totally 38 kg N ha^{-1} were supplied to okra with these fertilizers.

To determine the field capacity of the experiment area, three pooling points which had 1m×1m size were prepared and then saturated with irrigation water. These pooling areas were covered with polyethylene to prevent evaporation. Non destroyed soil samples were taken after three days to determine soil moisture at field capacity and to determine unit weight. Soil moisture at wilting point was determined by using pressure chamber method (Table 1).

First irrigation and last irrigation were carried out on 28 June 2007 and 17.09.2007, respectively. Eleven irrigation were performed in irrigation season nearly with a week interval. Gravimetric soil samples were taken each plot from 0-30, 30-60 and 60-90 cm soil layers. The samples were weighed and dried at 105°C in an oven then soil moisture content ratios were determined as follows:

$$\theta_a = \frac{W_s - W_{ds}}{W_{ds} - W_t} \qquad \text{Eq. (1)}$$

θ_a is actual soil moisture ratio before irrigation, W_s is soil sample mass with sample cup (g), W_{ds} is oven dried sample mass with sample cup (g) and W_t is sample cup mass (g). After determination of soil moisture ratios of the plots, irrigation water amounts were determined as follows:

$$I = (\theta_{fc} - \theta_a) \cdot \frac{\gamma_s}{\gamma_w} \cdot D \cdot A \cdot C \qquad \text{Eq. (2)}$$

I is irrigation water amount (liters), θ_{fc} is soil moisture ratio at field capacity (g g^{-1}), θ_a is actual soil moisture ratio before irrigation (g g^{-1}), γ_s is soil unit mass (g cm^{-3}), γ_w is water density (1 g cm^{-3}), D is rooting depth for irrigation (600 mm), A is plot area (7.5 m^2) and C is a coefficient based on irrigation treatments. C are 1, 0.75 and 0.50 for I_{100}, I_{75} and I_{50} treatments, respectively. Irrigation water amounts of any plots were filled a barrel and then applied to plots by siphoning.

Evapotranspiration (ET) between two consecutive irrigations (evapotranspiration of the irrigation interval) was calculated by using water balance equation as follows:

$$ET = \frac{I}{A} + R + (\theta_{an-1} - \theta_{an}) \cdot D - d_p \qquad \text{Eq. (3)}$$

Where, ET is okra evapotranspiration (mm), I is irrigation water amount applied (liter), A is plot area (m^2), R is rainfall (mm), θ_{an-1} is root zone actual soil moisture ratio for n-1th irrigation event, θ_{an} is root zone actual soil moisture ratio for nth irrigation event, D is rooting depth for irrigation (600 mm) and d_p is deep percolation (mm). Deep percolation was estimated by using soil moisture contents for 60-90 cm soil layer. Soil moisture increment for this layer was considered as deep percolation but soil moisture decrement was calculated in crop evapotranspiration.

Totally twelve times harvests were performed. Three rows at the middle of plots were harvested by considering side effects. The harvested fruits were weighted as fresh and oven-dried at 70°C to a constant dry weight. After the last harvest, the plants were cut at 1 cm above the soil surface. Vegetative fresh mass of plants was weighed and then some plant samples were taken to determine dry matter contents. Total dry matter yield was calculated by summing vegetative and fruit dry yield. Plant heights and stem diameters were also measured at the last harvest.

Yield response factors of fresh and dry fruit yields were determined as follows (Doorenbos ve Kassam, 1986):

$$\frac{Y_m - Y_a}{Y_m} = k_y \cdot \frac{ET_m - ET_a}{ET_m} \qquad \text{Eq. (4)}$$

Where, Y_m is maximum fresh or dry fruit yield from I_{100} (kg/ha), Y_a are actual fresh or dry fruit yields from water stress treatments and k_y is yield response factor.

The experimental data were analyzed by SPSS 13.0 statistical analysis software. The General Linear Model procedure was used to perform analysis of variance. Duncan's multiple range test was used to separate means of the data found significant at less than 0.05 level.

RESULTS and DISCUSSION

Soil moisture content, irrigation and okra evapotranspiration

Sowing was performed in 20.05.2007 and last harvest was performed in 28.09.2007. Total growing season of okra lasted 131 days in Tokat/Turkey. Irrigation water amounts, rainfall in the growing season, soil moisture differences between sowing and harvesting, and water consumption of okra were listed in Table 2. Totally 11 times irrigations were carried out with one week interval. Irrigation amounts applied to the treatments changed significantly. Okra evapotranspiration (ET) varied 594-757 mm according to the treatments. These differences in okta evapotranspiration were found siginificant at $p<0.01$ probability level. The highest evapotranspiration were determined as 757 mm for I_{100} treatment and the lowest one as 594 mm for I50 treatment (Table 2). Okra exposed to I_{75} and I_{50} treatments were consumed 7.4% and 21.5% less water than water consumed in I_{100} treatment. Therefore, okra plants in I_{75} and I_{50} experienced light and moderate water stresses.

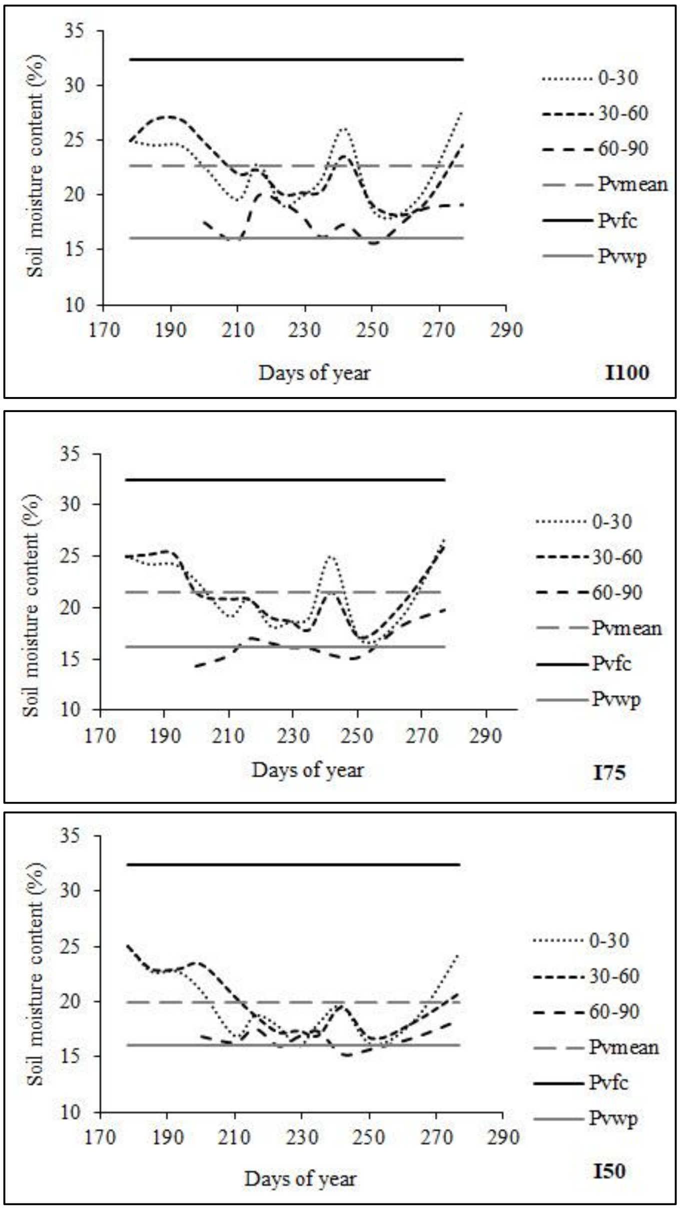
Table 2. Okra evapotranspiration (ET) and its components based on soil moisture budged.

	Rainfall (mm)	Irrigation (mm)	Deep percolation (mm)	Soil moisture difference (mm)	ET (mm)
I_{100}	73	606	-9	87	757
I_{75}	73	551	-10	87	701
I_{50}	73	422	-3	102	594

In an experiment, irrigation water amounts of 248 mm and 497 mm were applied to okra by alternate furrow and conventianal furrow irrigation methods, and okra yield 7.3% decreased at non significant level for alternate furrow irrigation method (Siyal ve ark., 2016).

Soil moisture content of treatments 1 day before irrigations were presented in Figure 2. Soil water contents fluctuated around 22.6% for I_{100}, 21.5% for I_{75} and 19.9% for I_{50} in growing season. Soil moisture contents in 60-90 cm soil layer below 60 cm-root zone were determined around 17.7%, 16.4% and 16.7% for I_{100}, I_{75} and I_{50}, respectively. Soil moisture contents in 60-90 soil layer for I_{100}, I_{75} and I_{50} were differed as 0.2%, 2.2% and -0.1% from soil moisture contents at the beginning of irrigation seasons. Mean soil moisture content in 60 cm-rooting depth at field capacity was determined as 32.4% and was as 16.1% at wilting point (Table 1). Therefore, total available soil moisture was 16.3% for the rooting depth. It can be concluded based on soil moisture graphics in Figure 2 that irrigations were performed at depletion factors around p= 0.60 for I_{100}, p= 0.67 for I_{75} and p= 0.77 for I_{50}.

In a two-year experiment (Panigrahi ve Sahu, 2013), okra irrigations were performed when 25% and 50% of available soil moisture were depleted. Okra yields for partial root zone irrigation were reported as 12,883.6 kg ha^{-1} and 12,858.9 kg ha^{-1} at available water depletion factors of 25% and 50%. Okra yielded 16,771.5 and 16,008.4 kg ha^{-1} for full irrigation at the same water depletion factors, respectively. According to findings of Panigrahi and Sahu (2013), we can not see any yield differences between irrigations performed at these two water depletion factors. In our experiment, significant reductions in fresh pod yield of okra were observed when okra was irrigated after depletion of 60% available soil moisture (Table 3). Therefore, okra irrigations at around 0.5 water depletion factor appear suitable to obtaine higher yield.



Şekil 2. Volumetric soil moisture variations 1 day before irrigations for I_{100}, I_{75} ve I_{50} treatments

Okra dry biomass yield, fresh and dry pod yields

Total dry biomass yield of okra above soil surface varied between 4862 and 9119 kg ha^{-1} in this experiment. The dry biomass yield differences of okra were found significant at 0.05 level according to irrigation treatments. Dry biomass yields were found 7848 kg ha^{-1} for I_{100}, 6475 kg ha^{-1} for I_{75} and 5617 kg ha^{-1} for I_{50} (Table 3). Dry biomass yield for I_{75} was 17.5% lower than I_{100} and was 28.4% lower for I_{50}. Mean dry matter ratio of okra plant at harvest were determined as 24.6% while mean dry matter ratio of okra podes were determinden as 16%. Okra produced around 1.1 kg dry biomass yield above soil surface for each cubic meter water. Harvest index, which is ratio of dry pod yield to dry biomass, were found as 0.56, 0.58 and 0.66 for I_{100}, I_{75} and I_{50} treatments, respectively (Figure 3). Although an increasing harvest index trend with water stress were observed, differences among treatments were not found significant. But a strong strong negative relationship (R= 0.78) was found between okra evapotranspiration and harvest index or a positive relationship (R= 0.78) was found between okra relative evapotranspiration stress and harvest index (Figure 3).

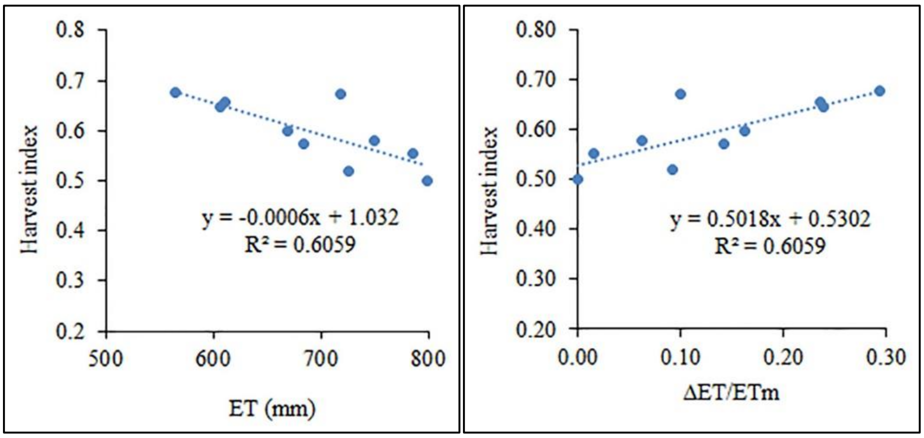


Figure 3. Relationships between evapotranspiration-harvest index and between water stress-harvest index.

Mean pod numbers per plant was determined as 45.2 and varied between 34.7 and 64 (Table 3). I_{100}, I_{75} and I_{50} treatments yielded 47.5, 46 and 41.4 pod number per plant but the differences among the treatments were not found significant. Mean fresh pod yield per plant was 472 g and varied between 344 g and 666 g. Averaged each fresh and dry pod weights were determined 10.4 g and 1.7 g, respectively. Irrigation regimes affected neighter pod yields per plant nor mean pod weight.

Mean fresh pod yield was found as 24864 kg ha^{-1} and varied between 17699 and 32092 kg ha^{-1}. Irrigation regimes affected fresh pod yield significantly ($p<0.05$). I_{100}, I_{75} and I_{50} treatments yielded 28226, 24619 and 20554 kg fresh okra pods per ha. The highest fresh yield was obtained from I_{100} and the lowest one was obtained from I_{50}. I_{75} and I_{50} treatments produced 12.5% and 27.2% less fresh pod than I_{100} although their evapotranspiration reduction ratios were 11% and 24%, respectively.

Okra yield in our experiment was found considerably higher than world okra mean yield 4013.8 kg ha^{-1} and than the highest yields as 14158 kg ha^{-1} obtained by Siyal ve ark (2016), 8100 kg ha^{-1} by Adekiya ve ark (2017) and 17150 kg ha^{-1} by Abubaker ve ark (2014).

Table 3. Okra fresh and dry pod yields, biomass, dry matter ratio and harvest index

Treatment	Plant Pod number	Mean Pod weight (g)	Plant pod yield (g)	Pod yield (kg ha^{-1})	Dry pod yield (kg ha^{-1})	Dry biomass (kg ha^{-1})	Pod dry matter ratio (%)	Harvest index
I_{100}	47.5	10.7	505	28226 a	4375	7848 a	15.50	0.56
I_{75}	46.0	10.4	481	24691 ab	3783	6475 ab	15.32	0.58
I_{50}	41.4	10.1	419	20554 b	3700	5617 b	18.00	0.66
Mean	45.2	10.4	472	24864	3994	6767	16.27	0.60

Water use efficiency and yield response factor of okra

Fresh pod yields between 4.51-4.89 kg, dry pod yields between 0.73-0.87 kg and dry biomass yields between 1.19-1.33 kg were obtained per 1 m^3 irrigation water. Fresh pod yields between 3.46-3.76 kg, dry pod yields between 0.57-0.63 kg and dry biomass yields between 1.05-1.17 kg were also obtained per 1 m^3 consumed water (Table 4). Non significant differences for water use efficiencies were observed for the treatments.

Table 4. Okra irrigation water use efficiency (IWUE) and water use efficiency (WUE)

	Fresh pot		Dry pot		Dry biomass	
	IWUE (kg m^{-3})	WUE (kg m^{-3})	IWUE (kg m^{-3})	WUE (kg m^{-3})	IWUE (kg m^{-3})	WUE (kg m^{-3})
I_{100}	4.69	3.76	0.73	0.58	1.30	1.17
I_{75}	4.51	3.54	0.73	0.57	1.19	1.05
I_{50}	4.86	3.46	0.87	0.63	1.33	1.09
Mean	4.69	3.60	0.77	0.59	1.27	1.11

Irrigation water use efficiencies were determined as 5.29 kg m^{-3} for alternate furrow irrigation, as 2.78 kg m^{-3} for conventional furrow irrigation and as 1.37 kg m^{-3} for flood irrigation (Siyal ve ark., 2016). In an other experiment, irrigation water use efficiencies as 8.41-9.18 kg m^{-3} for alternate partial root zone irrigation, as 6.98-7.85 kg m^{-3} for fixed partial root zone irrigation and as 6.79-7.25 kg m^{-3} for full irrigation water use efficiencies were reported (Panigrahi ve Sahu, 2013).

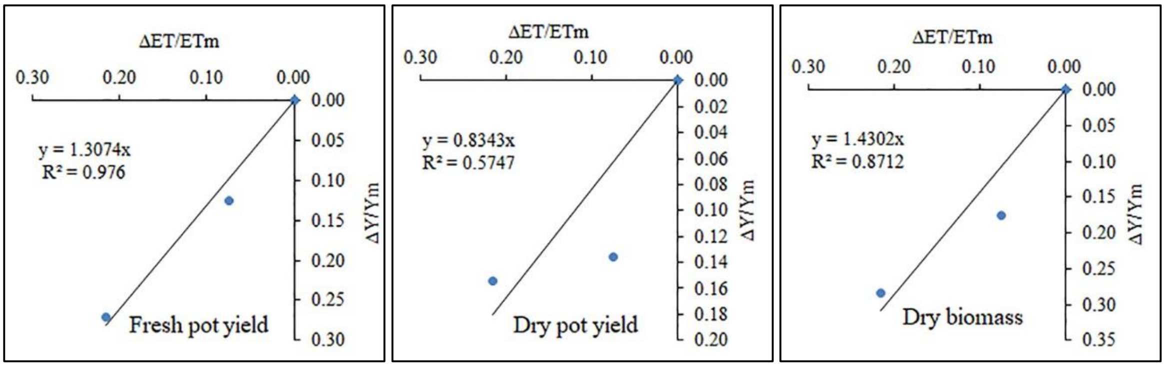


Figure 4. Relationship of okra between relative water consumption decrease and relative yield decrease

Okra was exposed to water stress along growing season, and yield response factors of okra were determined as k_y= 1.31 for fresh pod yield, as k_y= 0.83 for dry pod yield and k_y= 1.43 for dry biomass (Figure 4). Okra sensitivity to water stress was found sensitive for fresh pod and dry biomass yields but was found tolerant for dry pod yield. Although water consumption of I_{75} decreased only 7%, fresh and dry pod yield decreased 13 and 14%, respectively. Fresh and dry pod yield decreased 27% and 15%, respectively while water consumption of I_{50} treatment decreased 22%. Sensitivity difference in yield response factor for fresh and dry pod yield of okra resulted from dry matter content differences. Dry matter ratios of okra for I_{100}, I_{75} and I_{50} were found as 15.5%, 15.3% and 18%, respectively. For this reason, dry pod yield in I_{50} was relatively higher than fresh pod yield and higher dry pod ratio alleviated water stress effects, relatively. Okra dry biomass sensitivity to water stress was found higher than water stress sensitivity of fresh pod yield (Figure 4). From this finding and also from harvest index finding, we concluded that okra deliveres higher photoshenthetic matter to its pods than it deliveres to vegetative growth under water stress conditions.

CONCLUSIONS

Depleted water in 60 cm-rooting depth were applied with three different ratios (100%, 75% and 50%) to Akköy okra cultivar in this experiment, conducted in semi-arid Tokat/Turkey conditions. Fresh and dry pod yields, dry biomass, water consumption, water use efficiencies, harvest index and yield response factor of okra were investigated for full and deficit irrigation conditions. Conclusions based on findings of this experiment were listed briefly as follows:

Okra effectively used soil moisture stored in 60 cm rooting depth and did not uptake soil water below 60 cm soil layer considerably. Irrigation practices based on 60 cm rooting depth appears suitable for okra.

Irrigation practices were carried out after depletion of 60% of total available water or around p= 0.6 depletion factor and considerably higher pod yield was obtained under full irrigation conditions. Okra pod yield decreased when irrigation practices were performed with higher depletion factor big than 0.6. Therefore, irrigation of okra should be performed before depletion of 50% of total available soil moisture to produce higher yield.

Okra pod yield and dry biomass yield were decreased under water stress conditions but dry matter ratios of okra increased. Dry pod yield under water stress conditions decreased relatively less than fresh pod yield. Okra could be defined as sensitive to water stress for fresh pod yield but could be defined as tolerant for dry pod yield.

Okra harvest index was increased with increasing water stress. Therefore, okra preferred to hasten its pod yield instead of improving vegetative growth under water stress conditions.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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