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Effect of Planting Times and Saline Irrigation of Quinoa Using Drainage Water on Yield and Yield Components under the Mediterranean Environmental Conditions

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ABSTRACT

In regions where irrigation water supplies are limited, drainage water can be used to supplement them. Field experiments were carried out during the quinoa growing season of 2012 in Tarsus, Turkey in order to evaluate the effect of irrigation using drainage water and planting dates on yield and yield components of quinoa. The experiment was laid out using line-source irrigation system. A total of four irrigation levels (I1: full irrigation; I2 through I4: deficit irrigation levels) and a rain-fed treatment were considered. Quinoa (Chenopodium quinoa Willd.) titicaca variety was planted on April 11 as for normal planting and April 30 for late planting. The quality of drainage water varied from 1.27 to 1.68 dS/m. The results showed that irrigation levels and planting times produced significantly different yield and yield attributes. Normal planting time was superior to late planting. In general, quinoa grain yields in the normal planting plots were higher than late planting plots. Soil salinity in the top soil layer (30 cm) increased to 1.46 dS/m at harvest from 1.15 dS/m at sowing. Soil salinity decreased with increasing depth. Thus, the results revealed that drainage water can be used for irrigation of quinoa under water shortage conditions.

Keywords: *Drainage water reuse, water use efficiency, planting times, soil salinity*

INTRODUCTION

It is the biggest challenge of next century to meet food and fiber needs of ever increasing world population. Increasing production of cereals is therefore strategically very important to ensure food self sufficiency (Yazar *et al.* 2006). Food production and water use are inextricably linked. Water is the main factor limiting crop production in much of the world where rainfall is insufficient to meet crop demand. With the increasing competition for finite water resources worldwide and the steadily rising demand for agricultural commodities, the call to improve the efficiency and productivity of water use for crop production, to ensure future food security and address the uncertainties associated with climate change, has never been more urgent. Given current demographic trends and future growth projections, as much as 60% of the global population may suffer water scarcity by the year 2025 (UN-Water 2012). The water-use efficiency techniques used with conventional resources have been improved. However, water-scarce countries will have to rely more on the use of non-conventional water resources to partly alleviate water scarcity. In water-scarce environments, such water resources are accessed through the desalination of seawater and highly brackish groundwater, the harvesting of rainwater, and the use of marginal-quality water resources for irrigation (Qadir and Oster 2004). The marginal-quality waters used for irrigation consist of wastewater, agricultural drainage water, and groundwater containing different types of salts. The salinity and sodicity of drainage water are the main parameters that determine the feasibility of its reuse. A successful adoption of reuse will require an integrated approach requiring new and flexible on-farm skills related to irrigation, crop and soil management within the context of being economically feasible and environmentally sound (SJVDIP 1999; Corwin *et al*. 2008). The use of saline and/or sodic drainage water and groundwater for agriculture is expected to increase (Oster and Grattan 2002).

Re-use is an important and natural method of managing drainage water. In order to develop the maximum benefit from a water supply and to help dispose of drainage water, strategies for water re-use have evolved (Diaz *et al*. 2013). Water re-use must be balanced against both short and long-term needs, with consideration for both local and off-site effects. In regions where irrigation water supplies are limited, drainage water can be used to supplement them. However, the quality of the drainage water determines which crops can be irrigated. Highly saline drainage water cannot be used to irrigate salt-sensitive crops. It could, however, be re-used on tolerant forages or in a saline agriculture-forestry system. Saline drainage water is being successively re-used for the irrigation of salt-tolerant crops and trees. It is possible to safely re-use agricultural drainage water if the characteristics of the water, soil, and the intended crop plants are known and can be economically managed (Oster and Grattan 2002; Corwin *et al*. 2008).

Quinoa, traditional Andean seed crop, has been cultivated in the Peruvian and Bolivian Andes for more than 7000 years (Pearsall 1992). It is well adapted to grow under unfavorable soil and climatic conditions (Garcia *et al*. 2003) and the crop is also rapidly gaining interest throughout the world (Jacobsen 2003) because of its robust character and its high nutritional value. Apart from the high protein content and the balanced presence of essential amino acids such as lysine, the grains are also rich in vitamins and minerals (Jacobsen *et al*. 2005). Its robust character is due to a high tolerance level of frost (Jacobsen *et al*. 2005), drought (Geerts *et al*. 2008) and soil salinity up to 40 dS/m (Jacobsen *et al*. 2003; Razzaghi *et al*. 2011). In terms of basic characteristics, the plant is an annual crop species belonging to the C3 group of plants (Jacobsen *et al*. 2003). The 1000 grain mass is generally low due the small seed size (3–6 g) (Geerts *et al*. 2008). Different agronomic characteristics of a large number of quinoa varieties are listed by Bhargava *et al*. (2006).

The primary objective of this study was to evaluate the effect of supplemental irrigation and planting dates on quinoa yield and yield components, salt accumulation in soil and water use efficiency using saline drainage water in the Mediterranean region of Turkey.

MATERIALS AND METHODS

Experimental Site and Soil

The field experiment was carried out during the 2012 growing season on the experimental field of Soil and Water Resources Research Institute, Tarsus in the Mediterranean region of Turkey. Typical Mediterranean climate prevails in the experimental area. The station has a latitude of 37°01' N and, a longitude of 35°01' E and is at 10 m above mean sea level. The soil of experimental site is classified as Arikli silty-clay-loam with relatively high water holding capacity. Volumetric soil water contents at field capacity and permanent wilting point are 0.44 and 0.29%, respectively. The available water holding capacity of the experimental site was observed 158 mm in a 90 cm soil profile. Mean bulk density varies from 1.17 to 1.31 Mg/m^3. Soil salinity at different depths was evaluated on saturation extracts of the soil samples taken at the beginning and at harvest period.

Experimental Design and Treatments

The experiment was laid out using two line-source irrigation systems which allows a gradual variation of irrigation, in direction at right angle to the source (Hanks *et al*. 1976). Four irrigation levels, namely one full (I1) and three deficit (I2-I4) irrigations; and a rain-fed treatment were envisaged. I2, I3, and I4 treatments represent deficit irrigation of approximately 20, 50, and 80%, respectively. Double-nozzle sprinkler heads (4.5 mm x 4.8 mm) placed at 6 m intervals on the laterals, provide linearly decreasing wetting pattern under the pressure of 300 kPa. Layout of the line-source sprinkler system is shown in Figure 1.

Drainage water was applied to replenish soil water deficit in the 60 cm depth to the field capacity; for the 7-day irrigation interval in treatment plots adjacent to sprinkler lateral (I_1). Each treatment was replicated four times. Water samples were taken from a drainage canal in the experimental area at the beginning, during irrigations, and at harvest and the average electrical conductivity varied between 1.27 and 1.69 dS/m during the experiment. Salinity of drainage water decreased gradually from 1.68 dS/m in early April to 1.27 dS/m in early June, then started to increase in early July; and pH was 7.1. The drainage channel is a secondary canal serving an area of 60 ha of land in the experimental site.

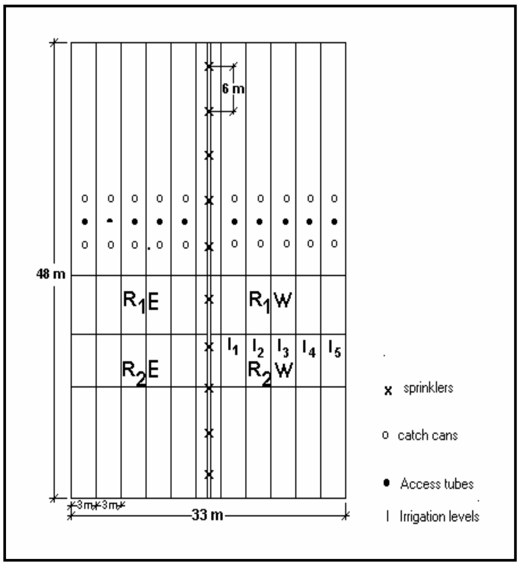

Fig1. *Layout of the line-source sprinkler system*

Agronomic Practices

In the study, two planting times (normal and late) were used. Normal planting and late planting was done on 11 April and 30 April 2012, respectively. In this study, *Chenopodium quinoa* Willd. L Titicaca variety was used. Quinoa seeds were provided to seedlings producing greenhouse approximately three weeks before the planting dates. Seedlings were transplanted at 20 cm in row, and 50 cm row spacing on April 11 and April 30, 2012 for normal and late planting, respectively. At both planting times 70 kg/ha composite fertilizer of 20-20-20% N-P-K was applied and incorporated into soil. On May 15, 2012 50 kg/ha urea (46% N) was applied. Quinoa was harvested on July 10, and July 20, 2012, for normal and late planted quinoa, respectively.

Measurements and Observations

The soil water content measurements were made at 7-day intervals for quinoa until harvest in the four replications for all treatments by gravimetric sampling in 0-30 cm, and using a neutron probe (Campbell Pacific model 503DR Hydroprobe) at 30 cm depth increments over 90 cm deep with 15-s counts. The probe was field calibrated for the experimental soil.

Plant and soil water measurements and observations were started after planting, and were terminated on the harvest date. At harvest, all plants in the two 2 m rows were cut at ground level and grain and straw were separated by hand and weighed. All plant samples were dried for 48 hours an oven at 68^{o}C for determination of dry matter production and grain moisture content. The harvest was done on 10 and 19August 2012 for normal and late planted quinoa, respectively.

Evapotranspiration (ET) was calculated with the water balance equation (Eq. 1):

$$ET=I+P\pm\Delta SW-Dp-Rf \qquad (1)$$

where; ET is evapotranspiration (mm), I the amount of irrigation water applied (mm), ΔSW the soil water content changes (mm), Dp the deep percolation (mm), and Rf amount of runoff (mm). Since the amount of irrigation water was controlled, deep percolation and run off were assumed to be zero.

Water use efficiency (WUE) was calculated as grain yield divided by seasonal ET; and Irrigation water use efficiency (IWUE) was estimated as grain yield divided by the seasonal total irrigation depth (Yazar *et al*. 2006).

Data were analyzed with a statistical software package developed for line-source sprinkler system (Hanks *et al*. 1980). Treatment means were compared using Fisher's least significant difference (LSD) test at P = 0.05.

RESULTS

Irrigation and Evapotranspiration

The amount of saline drainage water applied and seasonal water use, grain yield, water use efficiency (WUE) and irrigation water use efficiency values for normal and late planting times in the experimental years are given in Table 1. Applied water decreased with distance from the sprinkler line source in a fairly linear manner. Average water amounts ranged from 310-395 mm next to the sprinkler line (I_1), and from 71 to 95 mm in the I4 irrigation level. Seasonal water use varied from 208 mm in I_5 in the late planting and 473 mm in I_1 treatment plots in the late planting times. Evapotranspiration was significantly influenced by irrigation levels (P<0.023). Water use decreased with increasing distance from the line-source. The highest water use measured in the I_1 treatment for both irrigation intervals in the experimental years. The highest ET values were observed in I_1 treatment in the late and early planting conditions. Treatment of I_5 (rain-fed) had the lowest ET, which ranged from 208 to 222 mm in the late and early planting, respectively. Greater soil water deficit occurred in this season and quinoa experienced water stress in the severe deficit irrigation treatments. Soil water stress gradually increased towards the end of the growing season in the least watered treatment plots.

Table3. *Seasonal irrigation, water use, yield, water use efficiency, irrigation water use efficiency data of quinoa at in different treatments*

Planting times	Treatments	ET mm	I mm	Yield g/plant	WUE kg/m^3	IWUE kg/m^3
April 11 (Normal)	I_1	456(a)*	310	63.80a	1.40b	2.06b
	I_2	397(b)	236	57.70ab	1.45b	2.44b
	I_3	348(c)	165	45.50b	1.31c	2.76b
	I_4	262(d)	71	41.10b	1.57a	5.79a
	I_5 (rainfed)	222(e)	-	22.10c	1.00d	-
	LSD	38.2		10.42	0.12	1.23
April 30 (late)	I_1	473(a)	395	26.10a	0.55b	0.66c
	I_2	391(b)	304	23.40a	0.60b	0.77c
	I_3	300(c)	201	22.50a	0.75a	1.12b
	I_4	236(d)	95	15.90b	0.67ab	1.67a
	I_5 (rainfed)	208(e)	-	11.00b	0.53b	-
	LSD	35.6		6.20	0.09	0.18

**Values followed by different letters in the columns indicate statistical significance at 5 % level.*

Grain Yield and Water Use Efficiency (WUE)

Irrigation levels significantly ($P \leq 0.045$) affected quinoa grain yield. In general, quinoa grain yields in the normal planting plots were higher than late planting plots. Thus, the differences in yield between the normal and late planting treatments are statistically significant. Highest grain yield of 63.80 g per plant (which corresponds to approximately 6380 kg/ha) was obtained from treatment plots adjacent to the line-source in I_1 treatment in the normal planting condition. For the late planting, highest grain yield was obtained in I_1 treatment plots as 26.10 g/plant (2610 kg/ha). The lowest yields were attained from the I_5 treatment plot as 2210 and 1100 kg/ha for the normal and late planting, respectively. Grain yields significantly decreased with decreasing amount of irrigation water. Severe deficit irrigation treatment (I4) received only 71 mm of water and produced 41.10 g/plant grain yield (4110 kg/ha) which is almost two fold increases in comparison to rain-fed (I5) treatment.

The results showed that grain yield, seasonal water use, water use efficiency (WUE) and irrigation water use efficiency (IWUE) depended on the controlled ranges of soil water content. Grain yield response to irrigation varied considerably due to differences in soil water contents and rainfall distribution during the growing seasons. Treatment I_5 in the normal and late planting times represents a severe soil water deficit condition. Mean grain yield of treatment I_5 was evidently lower than those the other treatments (Table 3), which showed that severe soil water deficit markedly decreased grain yield of quinoa treatments compared with other treatments. WUE ranged from 1.00 kg/m^3 in I_5 to 1.57 kg/m^3 in I_4 treatment under normal planting and from 0.53 (I_5) to 0.75 kg/m^3 (I_3) under the late planting treatments. IWUE values ranged from 2.06 to 5.79 kg/ m^3 for normal planting time, and from 0.66 to 1.67 kg/m^3 for late planting. IWUE values increased with decreasing irrigation amounts for both planting times.

Yield Attributes

Average values of grain yield, plant height, 1000 seed weight and harvest index under the different planting times and irrigation treatments are given in Table 4. Plant height values in different treatments at harvest varied from 50.8 to 75.3 cm in the normal planting; and from 47.0 to 75.3 cm in the late planting times. I_1 treatment resulted in the highest plant height in each planting times. Mean plant height values were significantly affected both by the irrigation times and irrigation levels. As the amount of irrigation water applied decreased plant height decreased significantly. Other yield attributes such as 1000-grain weight values varied from a low of 3.03 g to maximum of 3.29 g in the normal planting and ranged from 2.62 to 2.79 g in the late planting conditions. 1000-grain weights increased with increasing distance from the lateral. In other words, as the amount of irrigation water decreased 1000-grain weight increased. The effects of irrigation treatments on 1000-grain yield for both planting times were found to be not statistically significant. Harvest index (HI) values were significantly higher for normal planting time than the late planting. HI values ranged from 30.9 to 36.6% for normal planting; and from 28.7 to 30.0 % for late planting. Full irrigation in normal planting resulted in the lowest HI of 30.9%.

Table4. *Grain yield, plant height, dry matter yield, 1000 seed weight and harvest index (HI) values under the different treatments*

Planting times	Treatment	Plant height, cm	Dry Matter g/plant	Grain yield, g/plant	1000 seed weight, g	HI %
Normal	I1	75.3 (a)	142.4 (a)	63.8 (a)	3.03 (ns)	30.9(b)
	I2	64.3 (b)	109.4 (ab)	57.7 (ab)	3.10 (ns)	34.5(a)
	I3	63.0 (b)	83.1 (bc)	45.5 (b)	3.11 (ns)	35.4(a)
	I4	57.0 (bc)	71.3 (cd)	41.1 (b)	3.27 (ns)	36.6 (a)
	I5	50.8 (c)	40.8 (d)	22.1 (c)	3.29 (ns)	35.1(a)
	LSD	5.96	37.46	16.24		
Late	I1	71.3 (a)	64.9 (a)	26.1 (a)	2.62 (ns)	28.7(ns)
	I2	68.5 (ab)	55.7 (a)	23.4 (a)	2.67 (ns)	29.6(ns)
	I3	63.0 (bc)	54.5 (a)	22.5 (a)	2.75 (ns)	29.2(ns)
	I4	58.0 (c)	38.6 (b)	15.9 (b)	2.72 (ns)	29.2(ns)
	I5	47.0 (d)	25.5 (c)	11.0 (b)	2.79 (ns)	30.1(ns)
	LSD	5.47	21.78	6.12		

LSD at %5 significance level.

Dry matter yields (DM) were significantly affected by planting dates ($P<0.023$) and irrigation levels ($P<0.012$). Normal planting time resulted in greater dry matter yield than the late planting time. Dry matter yield increased with increasing irrigation amounts. Full irrigation at normal planting time produced the maximum dry matter yield. On the other hand, rain-fed treatment had the lowest DM.

Grain Yield-Evapotranspiration and Irrigation Relations

The relationships between seed yield and crop water use is shown in Figure 2. Significant linear relationship for normal planting time, and second order polynomial relation were found between the seed yield and ET under the normal and late planting times ($R^2=0.912$ and 0.899 for normal and late planting, respectively). Quinoa seed yield increased with increasing ET in the normal and late planting times. Water use decreased significantly in the treatment plots received low irrigation amounts. Yield reached its maximum value at a seasonal ET of 456 mm then started to decrease with ET. When ET is relatively low, water availability is the limiting factor for grain yield and an increase in ET results in significant increases in grain yield.

The relationships between irrigation water and yield of quinoa are best described by a strong polynomial function for each planting time (Fig. 3). When the slope of the relationships were compared, greater slope was found in normal planting time. Thus, the effect of irrigation for normal planting is greater than the late planting. Late transplanted quinoa seedlings faced higher temperatures than the normal planting time so that it resulted in lower grain and biomass yields, and shorter plants.

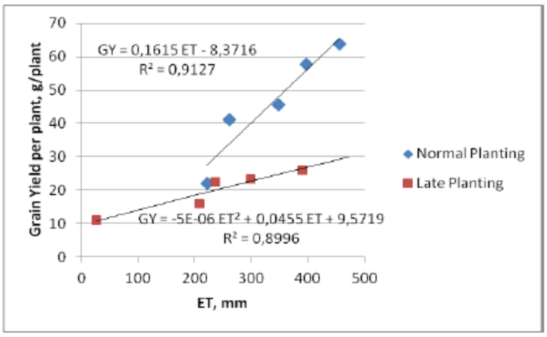

Figure2. *ET-Yield relationships under different planting times on Quinoa*

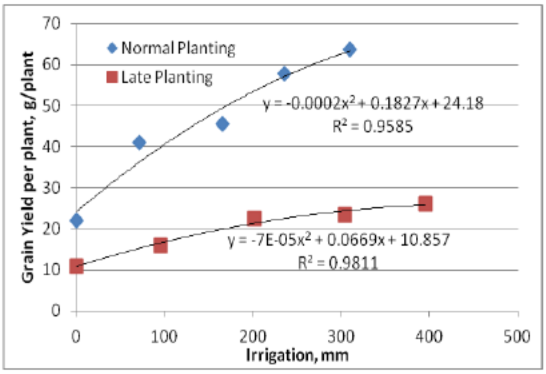

Figure3. *Irrigation-Yield relationships under different planting times on Quinoa*

Soil Water Storage Variations

Profile soil water storage variations during the 2012 growing season for each planting time are shown in Fig. 4 and 5, respectively. Soil water contents in the 0.60 m profile decreased gradually from DAP 20 until 90 DAP in all treatments in the normal planting. Available soil water in I_1 treatment plot remained above 40% throughout the growing season in the normal planting. On the other hand, almost all treatment plots except I1 and I2 treatment, available water fell below 40% after 35 DAT during the growing season and resulted in both lower yields. In the late planting treatment plots, available soil water in I_1 and I_2 treatment plots remained above 40% throughout the growing season. Thus, water stress gradually increased in the late planting treatments, and reduced yield significantly. Normal planting with high full irrigation created favorable soil water environment for quinoa growth and resulted in higher yields. Although quinoa is classified as drought tolerant crop, irrigations increased quinoa grain and biomass yields significantly. Soil water deficit increased gradually towards the end of the growing season and almost reached wilting point in I4 and I5 treatment plots.

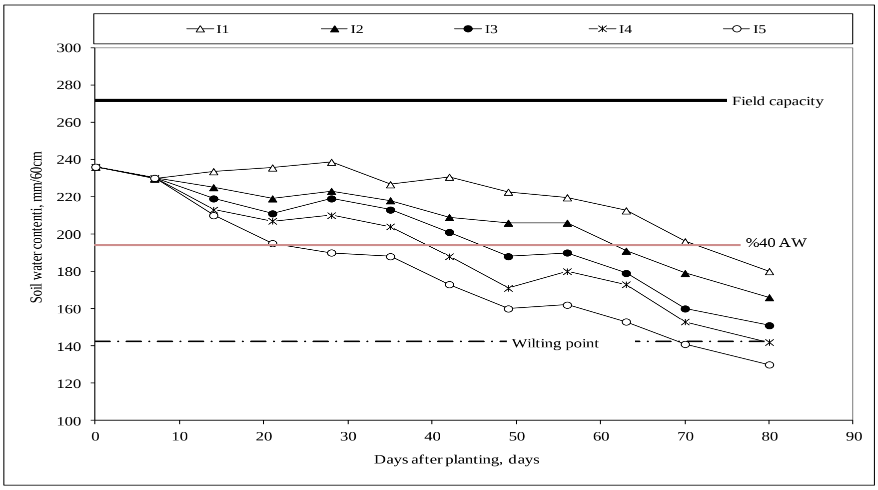

Figure4. *Soil water storage variation in all treatments during the growing season of quinoa for late planting*

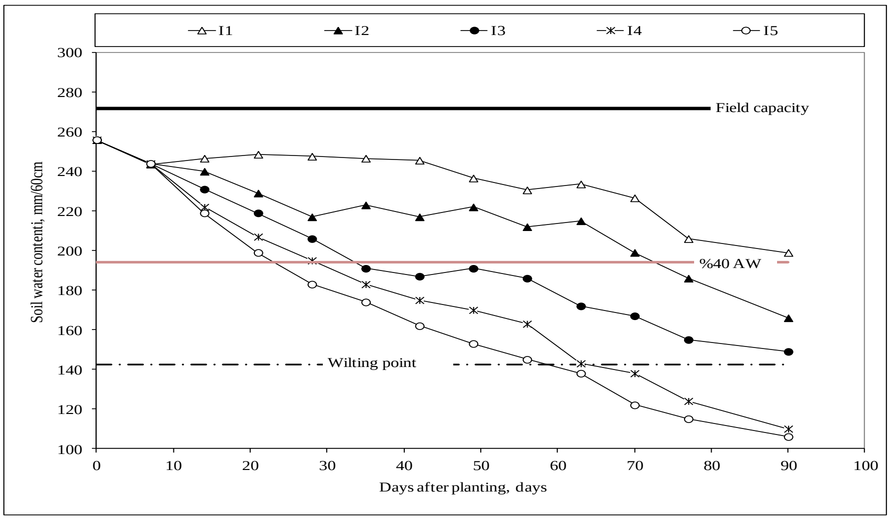

Figure5. *Soil water storage variation in all treatments during the growing season of quinoa in normal planting.*

Soil Salinity

Pre-experiment soil electrical conductivity (ECe) in the top 0-30 cm depth was 1.15 dS/m, which didn't change much in the deeper layers. At the 30-60 cm depth, soil ECe was 1.16 dS/m and it was 1.18 dS/m at the 60-90 cm depth. In the post-experiment soil samples from these three soil depths in all treatments, there was increase in soil ECe in the irrigation treatments with soil ECe levels reaching 1.46 dS/m in I1 treatment (Figure 6). The increase in this treatment resulted from the addition of salts through drainage water, which was used for irrigation. It had ECe levels ranging from 0.57 to 1.69 dS/m during the experimental period. The minimal increase in soil ECe (1.29 dS/m) was in the supplemental irrigation where minimum amount of water was used for irrigation (21 mm). The soil ECe levels didn't change much in the I5 treatment where no supplemental irrigation was undertaken (rainfed). Although there was an increase in soil ECe levels in all the irrigation treatments, this increase was not significant and the soil didn't reach higher levels of ECe. This was due to drainage water used for irrigation had ECe ranging from 1.27 to 1.69 dS/m during the experimental period.

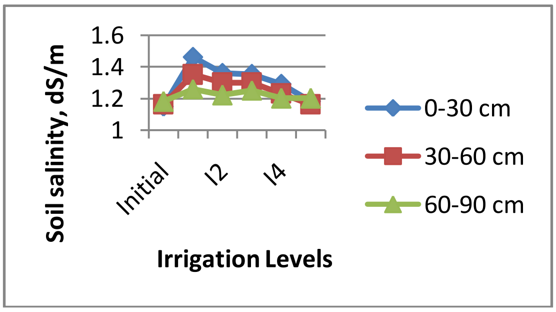

Figure6. *Effect of irrigation treatments on soil electrical conductivity (ECe) levels expressed as dS/m.*

DISCUSSIONS

With the increasing problems of disposal of saline drainage water and expanding demands on high-quality water for other purposes, on-farm management of saline drainage water for crop production has gained recognition. Various strategies have been proposed to use drainage water for irrigation. Selection of a particular strategy depends upon the quality of drainage water, soil type, crops to be irrigated and the agro-climatic conditions.

In this study, our results demonstrate that the effects of quinoa planting times, irrigation water amount applied with a sprinkler system and water use are significantly important in order to obtain higher yields of quinoa under climatic conditions of the Tarsus plain in Turkey. Evapotranspiration, grain yield and WUE of quinoa were all affected by controlled ranges of soil water content during the growing season. Grain yield response to irrigation varied considerably due to differences in soil moisture contents and rainfall among seasons. Highest average grain yield per plant (63.80 g/plant) was obtained from the full irrigation treatment (I_1) with normal planting time. Planting times affect quinoa yield; however, deficit irrigation affected crop yields by reducing grain weight. Thus, deficit irrigation of quinoa is not recommended for the region. The sprinkler system permitted precise control of irrigation applications. With proper management, sprinkler irrigation can avoid some application losses, which are inevitable with surface methods. Drainage water can safely be used for irrigation of quinoa, which is relatively tolerant to salinity. Winter rainfalls are sufficient enough to leach out the salts from the profile so no serious salt accumulation occurs during quinoa growing seasons. Soil salinity in the top soil layer (30 cm) increased to 1.46 dS/m at harvest from 1.15 dS/m at sowing. Soil salinity decreased with increasing depth. The winter rainfalls (annual rainfall is 650 mm; and 65% of it falls during winter period) leached the salts out of the crop root-zone prior to the new growing season.

In areas with improperly distributed rainfall, irrigations should be scheduled to replace water used for ET, or slightly increase it for highest yield. Yield and yield components, WUE of quinoa are differently affected by water stress in relation to its timing and intensity. The large variations in grain yield, WUE, between planting times can be attributed to seasonal differences in the distribution of rainfall during the growing stages of quinoa. The high correlation between grain yield and ET in this study indicates that grain yield is strongly influenced by the pattern of water use during the course of the season and emphasizes the importance of adequate water supply during all growing season for higher yield and WUE.

Saline drainage water reuse might be more practical in areas where non-saline water is available during the early growing season but limited in supply to meet the crop water requirements for the entire irrigation season. In arid and semi-arid regions, underground waters are of poor quality and supply of fresh canal water is not sufficient to meet the irrigation requirements of the entire area. In such situations the reuse of drainage water may be useful for crop production (Sharma and Tyagi 2005). Production systems based on salt-tolerant plant species using drainage waters may be sustainable with the potential of transforming such waters from an environmental burden into an economic asset. Such a strategy would encourage the disposal of drainage waters within the irrigated regions where they are generated rather than exporting these waters to other regions via discharge into main irrigation canals, local streams, or rivers. Being economically and environmentally sustainable, these strategies could be the key to future agricultural and economic growth and social wealth in regions where salt-affected soils exist and/or where saline-sodic drainage waters are generated.

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