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Growth, yield, water use and crop quality responses of lettuce to different irrigation quantities in a semi-arid region of high altitude

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Abstract

Water stress under reduced irrigation conditions affects plant physiology and hence yield and crop quality. Moreover, high altitude climatic conditions can significantly influence plant physiology. Therefore, a two year field study was conducted to determine the effects of different irrigation quantities on plant growth (leaf number, stem diameter, plant diameter and height), marketable yield, water use and crop quality attributes (mineral content, total phenolics and antioxidant activity) of drip-irrigated lettuce in a semi-arid region with a high altitude. A randomized complete block design was used for testing of different irrigation quantities replicated three times. Different irrigation quantities were adjusted considering 100 (I1), 85 (I2) and 70% (I3) of evaporated water from a Class A pan. Lettuce evapotranspiration was the highest in the I1 treatment (214.1 mm) considering the two year average values. Therefore, the I1 treatment provided the maximum growth and marketable yield (2.17 kg m^{-2}). Water use efficiency was also the highest in the I1 treatment (10.2 kg m^{-3}) because the lettuce yield decreased significantly with the decreasing irrigation quantity. However, total phenolic content and antioxidant activity in lettuce leaves were the highest in the I3 treatment. Moreover, I2 and I3 treatments provided higher mineral contents. While the potassium content in leaves was the most abundant among macro minerals (N, P, K, Ca, Mg, S, and Na), manganese content was the highest among micro minerals (Fe, Cu, Mn, Zn, and B). It could be said that lettuce can be irrigated with less irrigation quantities for obtaining higher mineral contents, total phenolic contents and antioxidant activity. This application can also provide water saving but cannot induce water productivity.

Key words: Antioxidant activity, marketable yield, mineral content, total phenolics, water productivity

Introduction

It is obvious that worldwide fresh water resources are limited and are not enough to meet demands (agriculture, industry, domestic use) of growing population. The water withdrawal for agriculture sector is 70% of the total withdrawals on a globe scale. Demographic projections show that the world population will be 9.3 billion by 2050. Global water demand is also estimated to increase by some 55% by 2050. It is expressed that 870 million people are undernourished because a lack of food or a lack of access to food (UNESCO, 2014).

Deficit irrigation in arid and semi-arid regions with limited water resources is a strategy to save water. A reduction in yield by a decrease in biomass production is appeared under water deficit conditions. However, it was indicated that the regulated deficit irrigation practices improved the water productivity in many horticultural plants and also increased farmers' net income (Fereres and Soriano, 2007).

The vegetables including the minerals, protein, vitamins, and dietary fibres provide balanced nutrition in the human. Also, vegetables is a good source of antioxidants (Gacche *et al.,* 2010). Therefore, vegetable production to provide the nutritional security has increased remarkably worldwide. One of the most important vegetable producers in the World is Turkey (Ekinci and Dursun, 2009). Turkey which has different geographical regions including mountainous regions, plateaus, plains, coastal regions, deltas etc. provides favorable ecological conditions for growth of many vegetables. Lettuce is produced in large quantities and also consumed as salad vegetables. Turkey lettuce area and yearly production were 8706.2 ha and 155179 ton, respectively (TSI, 2015).

Lettuce is a shallow-rooted crop and is also susceptible to water stress (Allen *et al.,* 1998; Molina-Montenegro *et al.,* 2011). Kuslu *et al*. (2008) reported that the marketable yield, and macro and micro-element contents of lettuce irrigated with level-basin method under open field conditions significantly decreased in the lower irrigated conditions. Molina-Montenegro *et al.* (2011) obtained that the photosynthetic rate and biomass production in lettuce was significantly lower in the treatment receiving 50% of irrigation water compared to the treatments receiving 100 and 75% of irrigation water. Yazgan *et al.* (2008) found that lettuce yields in unheated greenhouse condition significantly decreased with lower water applications, and the relationship between evapotranspiration and yield was linear. However, Capra *et al.* (2008) determined strong polynomial relationships between total water amount received and marketable yield of lettuce in two consecutive summer crop production conditions.

Temperature is one of the most important climatic factors in the crop production. Photosynthesis, respiration, transpiration, plant phenology and finally crop yield may be affected significantly with temperature (White and Howden, 2010; Hasanuzzaman *et al.,* 2013). The photosynthesis, respiration and growth increases with temperature up to the optimal limits. There is a positive correlation between temperature and photosynthesis (Hasanuzzaman *et al.,* 2013). Therefore, photosynthesis is affected seriously in cold regions (Theocharis *et al.,* 2012), the regions in high altitude where generally temperature decreases with increasing altitude create difficult environmental conditions for vegetable production. Therefore, phenological development is especially important in cool high altitudes (White and Howden, 2010).

Phenolic compounds present in plant foods have antioxidant, antimicrobial, anticancer, anti-obesity, anti-diabetic, anti-hypertensive and anti-mutagenic properties (Kunyanga *et al.,* 2012). Antioxidants protect against oxidative damage and so cancer and cardiovascular disease risk decreases in humans. Therefore, consumption of fruit and vegetables has been considered as an important component of a healthy diet which help to prevent of chronic diseases (Wang *et al.,* 2014). Especially, the consumption of leafy vegetables is major source of vitamins and micro-nutrients required for normal body functions in humans (Gacche *et al.,* 2010). Moreover, lettuce includes major phenolic compounds with antioxidant properties which are health-promoting phytochemicals (Oh *et al.,* 2009, 2010).

Previous studies have shown that less irrigation reduced crop yields. However, severity of water deficiency may change in different climates and lettuce production may be more adversely affected. Moreover, the changes of minerals, total phenolics and antioxidant enzyme activity under less irrigation conditions have not been observed sufficiently, especially in high altitude conditions. The purpose of the study was to evaluate mineral content, total phenolic content and antioxidant activity, and also marketable yield, growth (leaf number, stem diameter, plant diameter and height) and water use of the lettuce drip-irrigated with different irrigation quantities adjusted considering evaporation from a Class A pan in a semi-arid region with a cool climate under high altitude conditions.

Materials and methods

Experimental site, climatic conditions and soil properties: The present work was performed at the agricultural experimental station of Ataturk University with the altitude of 1796 m (a.s.l.) in Erzurum, Turkey (39.933º N and 41.237º E) during 2010 and 2011 growing seasons. Climate of the study site is a semi-arid with annual precipitation of 403.3 mm according to the long-term climatic data (1950-2014). Experimental region according to the map of Köppen−Geiger Climate Classification has a Dsc climate (D: snow, s: summer dry, c: cool summer) (Kottek *et al.,* 2006).

Lettuce (*Lactuca sativa* L. cv. Funly) was cultivated from 27 May to 18 July in 2010 and from 7 June to 28 July in 2011. Values of climatic parameters (temperature, relative humidity, wind speed, daily sunshine, precipitation and evaporation) in the experimental region during growing periods in trial years are given in Table 1 as monthly average or total. The average temperatures in 2010 and 2011 growing periods were 16.8 and 17.2 ºC, respectively. Precipitation and evaporation values were measured using a standard pluviometer and Class A pan located in the experimental site, respectively. The others were collected from records of Erzurum meteorological station (39.95° N, 41.17° E, 1757 m a.s.l.) at approximately 5 km distance from the experimental area.

The soils of the region covering experimental field is Aridisol according to the US Soil Taxonomy (Soil Survey Staff, 1992). Prior to the experiment, the basal soil properties in the top soil layer of 30 cm considering lettuce effective rooting depth were determined using standard procedures described by Klute (1986) and Page *et al.* (1982). The pH, electrical conductivity, organic C, $CaCO_3$, bulk density, field capacity and wilting point values were 7.47, 1.26 dS m^{-1}, 1.45 g kg^{-1}, 2.26%, 1.32 Mg m^{-3}, 28.8% and 16.9%, respectively. Also, soil texture was clay loam (29.5% clay, 34.2% silt and 36.3% sand).

Agricultural practices: A randomized complete block design was used for testing of different irrigation quantities (I1, I2, and I3) replicated three times. Therefore, nine plots were arranged in this experiment. Irrigation quantities for the I1, I2 and I3 treatments were adjusted considering the 100, 85 and 70% of the cumulative evaporation from a Class A pan located in the trial field. Each replicate was represented by a plot of 16 m^2 (2 x 8 m). Lettuce seedlings were planted in rows at 0.50 m-distance, and each seedling was separated from the other by 0.50 m. There were four plant rows on each plot. Manure at the amount of 30 Mg ha^{-1} was applied over the whole experimental field during soil preparation in first trial year. Needed hoeing was done manually. Pesticide or herbicide was not applied during trial years. Scheduled irrigations were initiated on June 14 in 2010 and on June 24 in 2011. Before scheduled irrigations, plants in all treatments received same amount irrigation water. In this period, irrigation quantities was equal to the amounts of water evaporated from the Class A pan. In scheduled irrigation period, plants were irrigated considering three different levels (1.0, 0.85 and 0.70) of water evaporated from the Class A pan. The irrigations were done when the total amount of evaporated water from the Class A pan was approximately 30 mm. Irrigation water was applied by drip irrigation system. The irrigation water volume applied to each plot was calculated using the equation:

Table 1. Monthly climatic data of the experimental area in the growing periods of lettuce in trial years

Year	Month	Climatic parameters					
		Temperature (ºC)	Relative humidity (%)	Wind speed (m s^{-1})	Daily sunshine (h)	Pan evaporation (mm)	Precipitation (mm)
2010	May[#]	12.6	66.4	3.1	9.0	17.8	1.0
	June	15.9	60.1	2.8	9.1	171.7	51.5
	July[&]	19.6	54.0	2.6	10.4	128.0	15.0
2011	June£	14.9	60.7	2.7	11.0	135.0	10.0
	July[$]	19.2	54.7	4.1	8.3	206.0	15.0

[#] Calculated from the data between 27-31 May. [&] Calculated from the data between 1-18 July.
[£] Calculated from the data between 7-30 June. [$] Calculated from the data between 1-28 July.

V= Epan x IL x P x A

where V is the irrigation water volume (L), Epan is the cumulative evaporation amount (mm) measured between consecutive two irrigation date, IL is the irrigation level (1.0 for the I1 treatment, 0.85 for the I2 treatment and 0.70 for the I3 treatment), P is the surface cover factor and A is the plot area (m^2). The P value for each treatment was determined with the ratio to plant row interval of plant cover width. It was considered 0.30 up to the scheduled irrigations. The maximum value for this ratio was 0.85 during growing period.

The pH, electrical conductivity and sodium adsorption ratio values of the irrigation water (groundwater) were 7.42, 0.29 dS m^{-1} and 0.57, respectively. In drip irrigation system, a dripline of 16 mm diameter which had in-line type emitters with a distance of 0.50 m was placed to each row. The emitter discharge rate was 4 L h^{-1} under an operation pressure of 0.1 MPa.

Harvesting, plant sampling and analysis: Fifteen lettuce plants on the middle of central two rows in each plot were harvested for analysis and measurements. The harvested plants were weighed after removal of outer discard leaves and roots to determine marketable head weight. Marketable leaf number, stem diameter, plant diameter and height were also measured. Marketable yield was expressed as g m^{-2}.

For the analysis of mineral contents in lettuce leaves, the leaves, washed with distilled water, were dried for 48 h at a constant heat of 68 °C in an oven and then dried leaves were powdered. The Micro-Kjeldahl method was used for determining N mineral content (Bremner and Mulvaney, 1982). P, K, Ca, Mg, S, Na, Fe, Cu, Mn, Zn and B mineral contents were measured after wet digestion using a HNO_3-H_2O_2 acid mixture (2:3 v/v) in a microwave unit (Speedwave MWS-2 Berghof products + Instruments Harresstr.1. 72800 Enien Germany) with three different steps (first step: 145°C, 75% RF, 5 min; second step: 180°C, 90% RF, 10 min and third step: 100°C, 40% RF, 10 min) (Mertens, 2005a). ICP-OES spectrophotometer (Inductively Couple Plasma spectrophotometer Perkin-Elmer, Optima 2100 DV, ICP/OES, Shelton, CT 06484-4794, USA) was used for mineral analyses (Mertens, 2005b).

The antioxidant activity and phenolic compounds were analyzed in solution collected from lettuce pulp. For preparing the solution, 10 g of lettuce pulp was mixed with 10 mL ethanol and stirred for 6 hours using a magnetic stirrer, and then stirred suspension was filtered through a Whatman No. l filter paper (Sengul *et al.,* 2011). Final solutions were kept in a freezer at a constant temperature of -20 °C until analysis. The analysis of the total phenolics content in the solutions was made by the Folin–Ciocalteau colorimetric method (Gülçin *et al.,* 2002) with analytical grade gallic acid as a standard. Antioxidant activity was determined according to the β-carotene bleaching method explained by Kaur and Kapoor (2002) with some modifications (Sengul *et al.,* 2011).

Evapotranspiration, water use and irrigation water use efficiencies: The crop evapotranspiration was calculated using the water balance method using the equation below (Allen *et al.,* 1998).

$$ETc = I + P + Cr - Rf - Dp \pm \Delta S$$

where, ETc is the crop evapotranspiration (mm), I is the irrigation water amount (mm), P is the precipitation (mm), Cr is the capillary rise (mm), Rf is the surface runoff (mm), Dp is the deep percolation (mm), and ΔS is the change of soil water content in root zone. Cr and Rf values were neglected in the calculations since there was no capillary rise due to deep water table in the experimental site and no runoff loss due to use of the drip irrigation method. The amount of water from irrigation or precipitation above field capacity in the effective root zone of 30 cm was considered deep percolation (drainage). Soil water contents for determining ΔS were measured gravimetrically during growing period and in the sowing and harvesting.

Water use of lettuce plants was evaluated with water use efficiency (WUE) and irrigation water use efficiency (IWUE) parameters. WUE (kg m^{-3}) is the ratio between the marketable yield (g m^{-2}) and seasonal crop evapotranspiration (mm). Similarly, IWUE (kg m^{-3}) is the ratio between the marketable yield (g m^{-2}) and seasonal irrigation quantity (mm) (Howell, 2001).

Statistical analysis: The examined data were evaluated statistically with ANOVA using MINITAB software. The significance means were ranked with the Duncan's Multiple Range test.

Results and discussion

Irrigation, precipitation and evapotranspiration quantities: As shown in Fig. 1, while the seasonal irrigation quantities applied to the I1, I2 and I3 treatments were respectively 173.6 mm, 143.8 mm and 111.2 mm in 2010 trial year, they were 175.3 mm, 142.2 mm and 109.6 mm in 2011 trial year. Precipitation values in the experimental area were 67.5 mm and 25 mm in 2010 and 2011 growing periods, respectively (Table 1). Monthly and seasonal crop evapotranspiration (ETc) values of lettuce determined considering irrigation and precipitation quantities, deep percolation and soil water content changes (Fig. 1). The highest seasonal ETc values were determined in the I1 treatment (204.9 mm in 2010 and 223.2 mm in 2011). Lower ETc values were determined in less irrigation conditions. Considering two year average values, the I2 and I3 treatments provided lower ETc values of 5.8% in 2010 and 16.2% in 2011 compared to the I1 treatment. Moreover, irrigation quantity in lettuce evapotranspiration was lower under reduced irrigation applications. The irrigation quantity compensation for lettuce evapotranspiration was 81.5, 70.9 and 61.5% in the I1, I2 and I3 treatments, respectively. It indicated that soil water potential was high in the less irrigation conditions. Therefore, lettuce evapotranspiration in the less irrigation conditions was decreased because increased water stress. The mean daily evapotranspiration values were 4.08 mm in the I1 treatment, 3.84 mm in the I2 treatment and 3.42 mm in the I3 treatment. Therefore, ratio of mean daily evapotranspiration values to the mean daily Epan values was 0.65 for I1 treatment, 0.61 for I2 treatment and 0.55 for I3 treatment.

Yield and its components: The results of the effects of different irrigation quantities on lettuce leaf number, stem diameter, plant diameter and plant height are given in Fig. 2. The highest growth parameters were observed in the highest irrigated (I1) treatment. Generally, the values of these parameters decreased with decrease

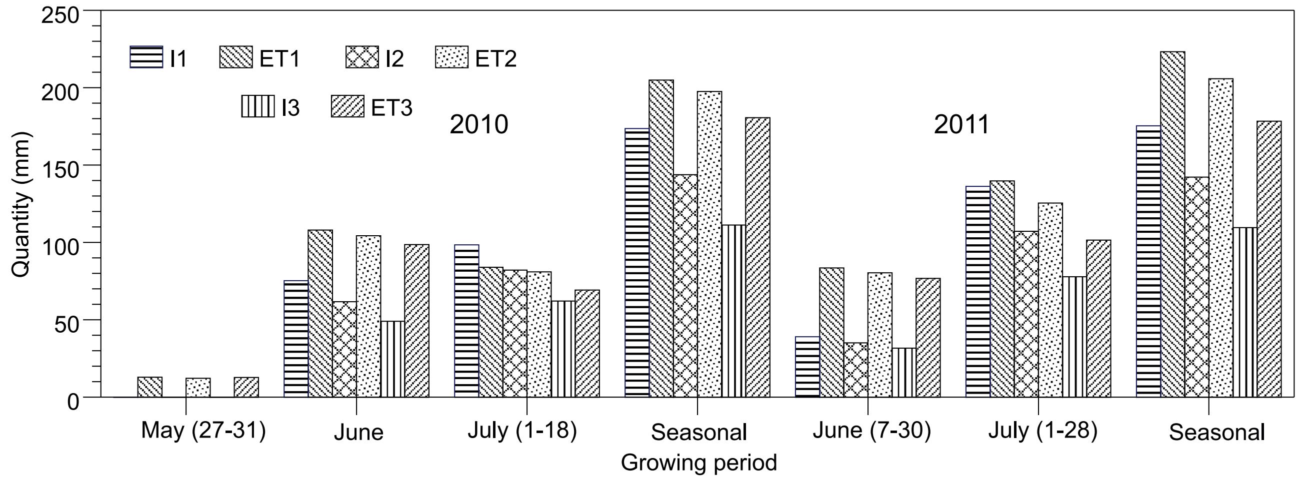


Fig. 1. Monthly and seasonal irrigation water (I) and evapotranspiration (ET) quantities of lettuce in the different irrigation levels in trial years

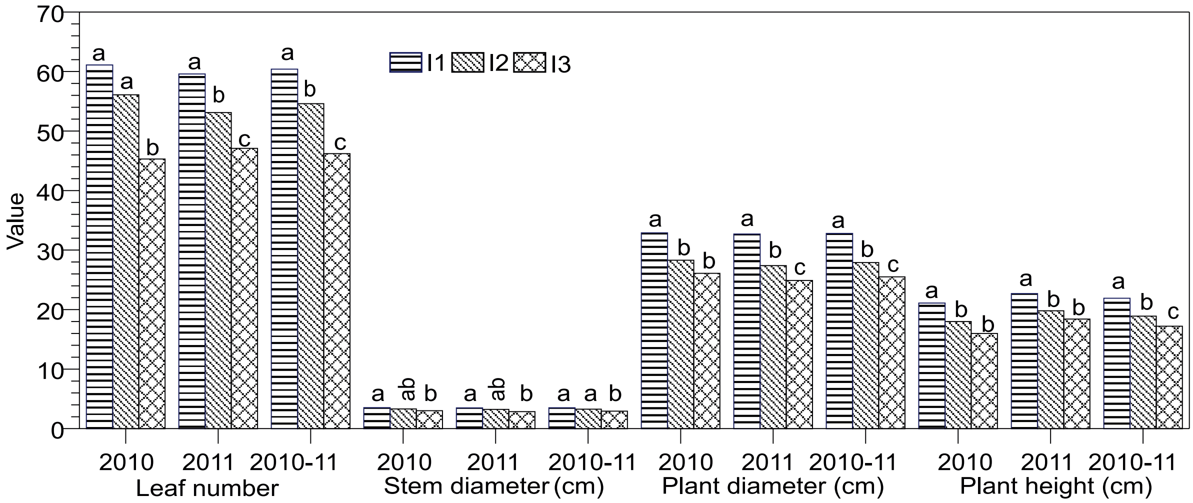


Fig. 2. Growth parameter values of lettuce in the different irrigation levels in trial years. Means marked with the same lowercase in each trial year for each parameter do not differ significantly ($P < 0.01$).

of irrigation quantities. Therefore, marketable yield of lettuce was the highest in the I1 treatment and decreased significantly ($P < 0.01$) with decrease of irrigation quantities in both trial year (Fig. 3). Although the I2 and I3 treatments received lower water quantities of 18.1 and 36.7% compared to the I1 treatment, the ratios of yield losses in these treatments were higher than the ratios of water deficiency. Considering two year average values, marketable yield in the I1 treatment was 36.1 and 91.2 higher than I2 and I3 treatments, respectively. It could be explained with the fact that lettuce plant is extremely sensitive to water deficit. Kizil *et al.* (2012) reported that the presence of water stress creates change in chemical pigment contents and cell structure that impedes photosynthesis and transpiration in plants. Moreover, lettuce is highly dependent on water to maintain high photosynthetic rates for obtaining fresh biomas with high commercial value (Molina-Montenegro *et al.,* 2011). Previous studies have shown that full irrigated lettuce provide significantly higher yields (Capra *et al.,* 2008; Kuslu *et al.,* 2008; Yazgan *et al.,* 2008; Mansuroglu *et al.*, 2010, Molina-Montenegro *et al.,* 2011; Chala and Yohannes, 2015).

Figure 4 shows strong linear relationships between marketable yield of lettuce with total irrigation quantity and evapotranspiration. These relationships revealed that less yield values was a result

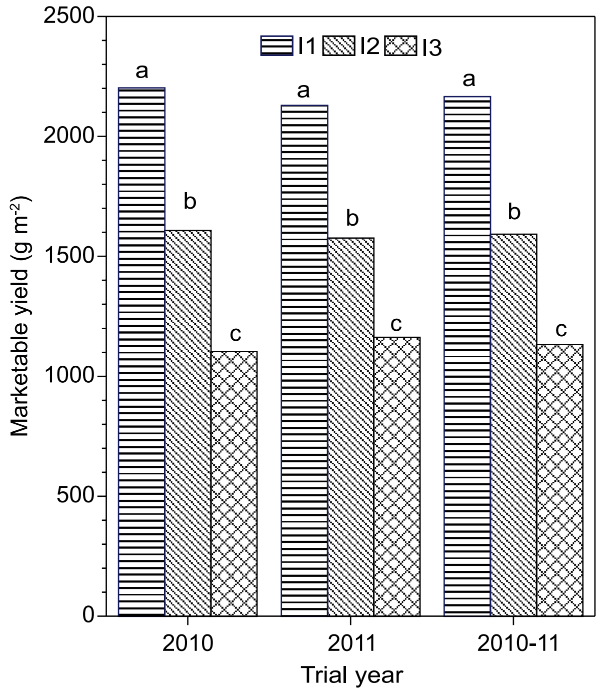


Fig. 3. Marketable yields of lettuce in the different irrigation levels in trial years. Means marked with the same lowercase in each trail year do not differ significantly ($P < 0.01$).

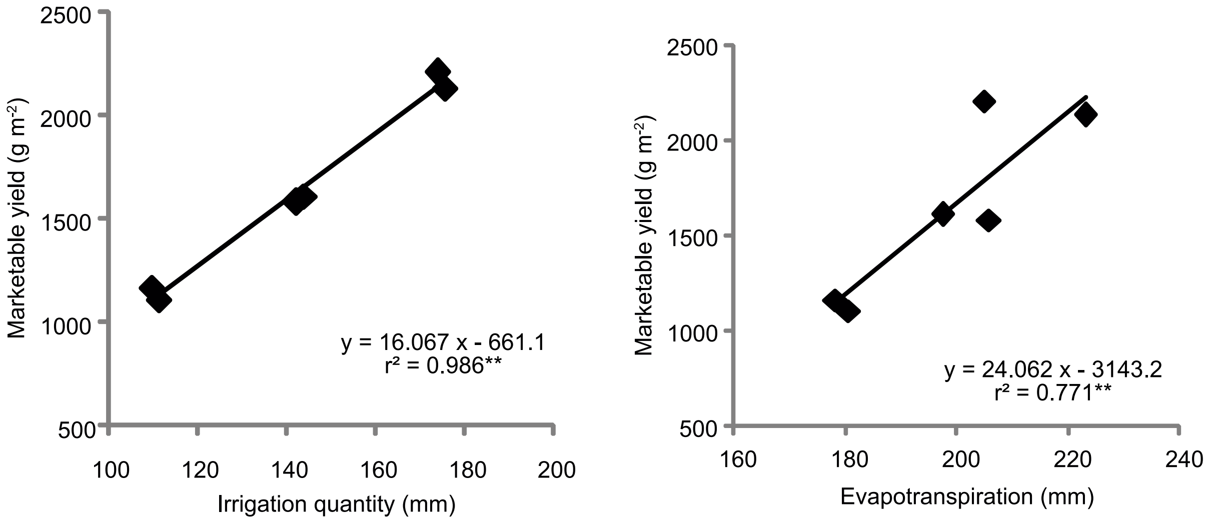


Fig. 4. The relationships between lettuce marketable yield with irrigation quantity and evapotranspiration (** $P < 0 .01$).

of less irrigation quantities. Kırnak *et al.* (2002), Kuslu *et al.* (2008), Yazgan *et al*. (2008) and Şenyiğit and Kaplan (2013) also reported significant linear relationships for between lettuce yield and water use. However, some researchers determined significant second degree polynomial relationships between lettuce yield and water use because the ratio of yield increase in the increasing irrigation conditions was lower than the ratio of water increase (Capra *et al.,* 2008; Bozkurt and Mansuroglu, 2011; Bozkurt and Mansuroğlu, 2011).

Water use efficiency (WUE) and irrigation water use efficiency (IWUE): The results of statistical analysis showed that the difference in irrigation levels significantly influenced the WUE and IWUE values. The WUE and IWUE values decreased with the reduction of irrigation quantity (Fig. 5). Considering two year averages, IWUE and WUE values were 12.4 and 10.2 kg m^{-3}, respectively. The IWUE values in the I2 and I3 treatments were 10.4 and 17.3% lower than the values in the I1 treatment. Moreover, the I2 and I3 treatments provided by 22.2 and 37.8% lower WUE values compared to the I1 treatment. Although the increase of water use efficiency is a strategy to contribute the sustainable use of limited water resources, the results of this study showed that water use efficiency in lettuce decreased in the less irrigation conditions. Therefore, results of this study were opposite to the results of different researches which show the water productivity increased in the decreasing irrigation conditions (Kırnak *et al.,* 2002; Bozkurt and Mansuroğlu, 2011; Chala and Yohannes, 2015; Gianino *et al.,* 2015). However, similar to present findings, some researchers also obtained higher water productivity values in the full irrigation conditions (Kadayifci *et al.,* 2004; Capra *et al.,* 2008; Kuslu *et al.,* 2008; Yazgan *et al.,* 2008; Şenyiğit and Kaplan, 2013).

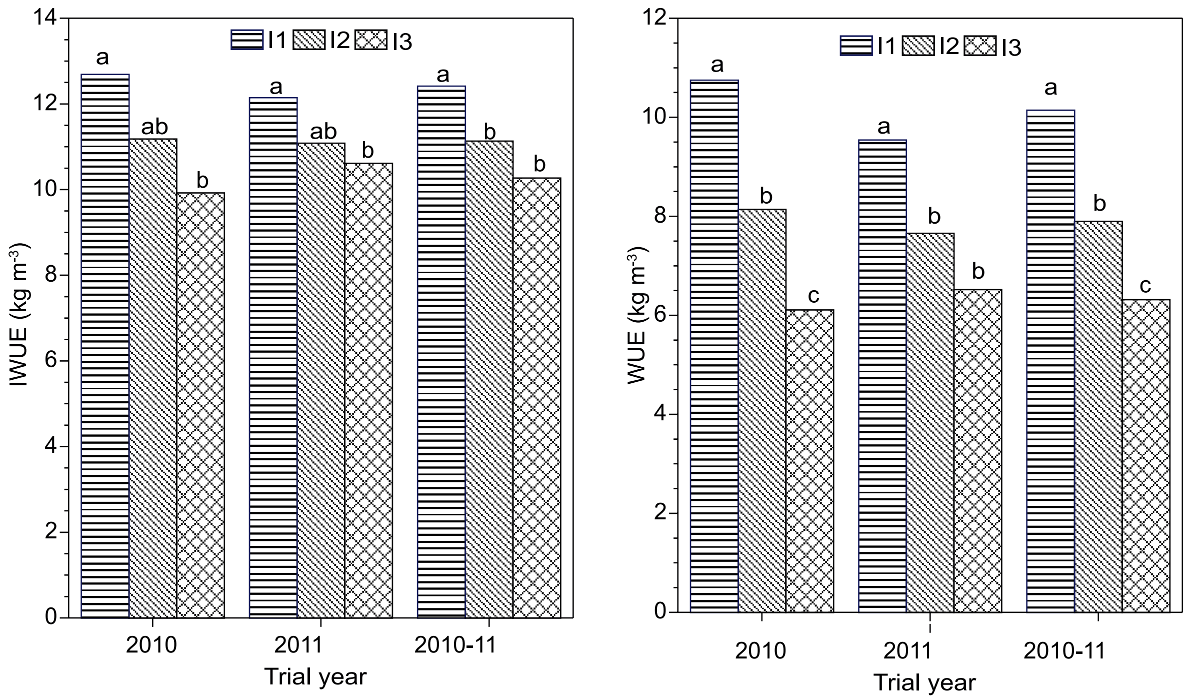


Fig. 5. Irrigation water use efficiency (IWUE) and water use efficiency (WUE) values of lettuce in the different irrigation levels in trial years. Means marked with the same lowercase in each trail year do not differ significantly ($P < 0.01$).

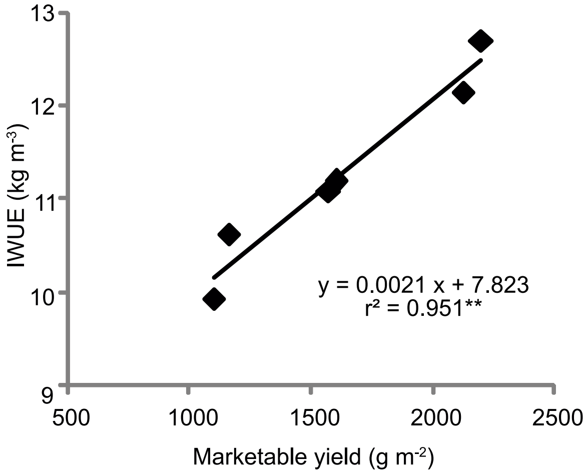
Table 2. Mineral content (mg kg^{-1} dry matter), total antioxidant activity and phenolic contents (mean ± SEM) in the leaves of lettuce in the different irrigation levels in trial years

Parameter	I1	I2	I3	*P* value
		2010		
N	22367±338 b	24500±346 a	23092±122 ab	0.005
P	5211±68.4 b	5546±27.3 a	5011±5.55 b	0.000
K	38775±195 a	36775±148 c	38023±20.3 b	0.000
Ca	14553±88.0 a	13099±10.9 b	14559±9.02 a	0.000
Mg	5411±83.9 b	5643±18.1 ab	5824±17.0 a	0.003
S	2871±34.5 c	3022±10.5 b	3198±3.84 a	0.000
Na	874±5.61 b	912±2.03 a	886±1.45 b	0.001
Fe	73.4±0.48 a	67.3±1.45 b	78.4±1.01 a	0.001
Cu	50.1±0.89 b	48.2±0.59 b	57.7±1.17 a	0.001
Mn	123±0.81 b	134±2.24 a	121±0.97 b	0.001
Zn	35.4±0.37 c	42.1±0.41 a	38.8±0.68 b	0.000
B	8.34±0.05 b	9.44±0.11 a	9.71±0.10 a	0.000
TAA	21.1±1.50 b	24.9±1.38 b	49.0±1.42 a	0.000
TPC	26.9±0.81 b	33.8±1.43 b	74.9±3.23 a	0.000
		2011		
N	24967±145 ab	24367±260 b	26267±376 a	0.011
P	5408±27.3 b	5621±35.9 a	5200±5.36 c	0.000
K	37211±254 b	39802±138 a	38011±23.5 b	0.011
Ca	13092±99.2 c	14344±63.3 b	14872±59.6 a	0.000
Mg	5012±38.5 b	5223±12.0 a	5310±7.42 a	0.000
S	2991±15.4 b	3210±6.57 a	2764±33.2 c	0.001
Na	987±8.95 a	1012±6.57 a	905±5.04 b	0.000
Fe	70.1±2.11 b	77.4±1.23 ab	82.1±0.89 a	0.001
Cu	56.2±1.00 b	62.1±0.38 a	50.3±1.58 c	0.002
Mn	143±1.24 a	150±1.76 a	127±1.64 b	0.001
Zn	30.2±0.75 b	38.1±0.24 a	40.2±0.44 a	0.002
B	10.2±0.05 b	12.3±0.68 a	9.86±0.02 b	0.008
TAA	21.3±1.22 b	25.6±0.39 b	48.8±0.95 a	0.001
TPC	26.5±0.59 c	34.3±1.29 b	74.7±1.43 a	0.000
		2010-11		
N	23667±604 b	24433±196 ab	24679±732 a	0.010
P	5309±55.0 b	5583±26.2 a	5105±42.4 c	0.000
K	37993±378	38288±683	38017±14.1	0.149
Ca	13822±332 b	13721±280 b	14715±75.0 a	0.000
Mg	5211±98.3 c	5433±94.4 b	5567±115 a	0.000
S	2931±31.7 b	3116±42.4 a	2981±98.2 b	0.000
Na	930.2±25.7 b	962±22.6 a	895±4.85 c	0.000
Fe	71.8±1.22 b	72.4±2.41 b	80.2±1.01 a	0.000
Cu	53.2±1.49	55.2±3.12	54.0±1.86	0.186
Mn	133±4.52 b	142±3.78 a	124±1.63 c	0.000
Zn	32.8±1.24 b	40.1±0.93 a	39.5±0.49 a	0.000
B	9.24±0.41 b	10.9±0.71 a	9.78±0.06 b	0.000
TAA	21.2±0.87 c	25.3±0.66 b	48.9±0.77 a	0.000
TPC	26.7±0.46 c	34.1±0.87 b	74.8±1.58 a	0.000

I1, I2 and I3 are irrigation levels equal to 100, 85 and 70% of evaporated water from a Class A pan, respectively.

Means marked with the same lowercase in each row do not differ significantly ($P < 0.01$ or $P < 0.05$).

TAA: Total antioxidant activity (%). TPC: Total phenolic content (μg GAE mg^{-1})



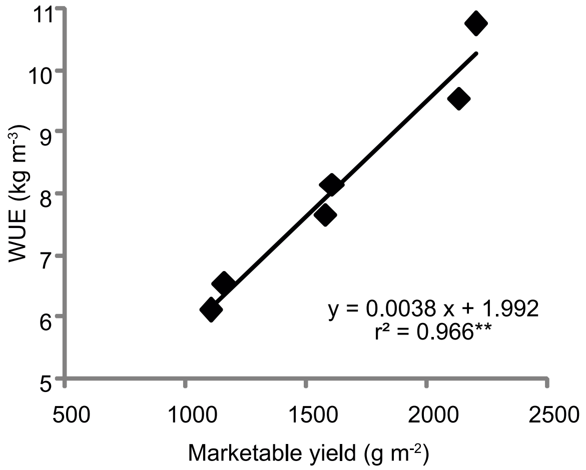


Fig. 6. The relationships between lettuce marketable yield with the irrigation water use efficiency (IWUE) and water use efficiency (WUE) (** $P < 0.01$)

Low IWUE and WUE values in the I2 and I3 treatments could be explained with more adverse effect on lettuce yield under less irrigation conditions. Fig. 6 also shows that there was strong linear relationships between marketable yield of lettuce with the IWUE and WUE.

Crop mineral content, total phenolics and antioxidant activity: Mineral contents in dry matter of lettuce leaves were significantly affected with irrigation quantities (Table 2). Considering average values of two years, while N, Ca, Mg and Fe contents were higher in the I3 treatment, the I2 treatment had higher P, K, S, Na, Cu, Mn, Zn and B contents. Potassium content was the highest among macro minerals (N, P, K, Ca, Mg, S, and Na). Considering the contents of micro minerals (Fe, Cu, Mn, Zn, and B), manganese content was the highest. Second abundant micro mineral was iron. Mineral accumulation order in the plants under the I2 treatment was K> N> Ca > P> Mg> S> Na> Mn> Fe> Cu> Zn > B.

Minerals are vital for human body functions. Calcium and phosphorus are required for body and bone structure development. Sodium and potassium are electron carrier in the body and iron is the constituent of hemoglobin (Hanif *et al.,* 2006). Manganese provides activation of several important enzyme systems. Magnesium which is an active component of several enzyme systems is also an important constituent of bones and teeth (Soetan *et al.,* 2010). Therefore, considering the results of this study it could be said that less water applications provided more health-promoting mineral contents in lettuce for human body. Plant nutrient uptake is influenced greatly by agricultural activities, climate, precipitation, root morphology, soil properties, fertilizing, and irrigation amounts (Akıncı and Lösel, 2012). The increasing of mineral content under lesser irrigation conditions in this study could be explained with the soil solute concentration increased with water deficiency led to an increase in plant mineral content (Bhardwaj, 2012). However, Sahin *et al.* (2015) and Kuslu *et al.* (2008) determined higher macro and micro element contents for lettuce in the full irrigated conditions. Akıncı and Lösel (2012) also reported that although many studies conducted on different plants stated that water stress mostly causes a reduction in mineral uptake, some of them also reported that increased with increasing water stress.

Total antioxidant activities and phenolic contents for experimental years are given in Table 2. Results showed an important an increase with decrease in irrigation quantity. The changes in total antioxidant activities under different irrigation applications were roughly parallel to the changes in the total phenolic contents. Considering two year averages, total antioxidant activities and phenolic contents in the I3 treatment were 2.3 and 2.8 times higher than the I1 treatment values, respectively. As similar to this study results, some studies conducted on lettuce have shown that total phenolic concentration and antioxidant capacity in lettuce increased with water stress. Oh *et al.* (2010) reported that the total phenolic concentration and antioxidant capacity in lettuce were significantly increased under mild water stress conditions. Eichholz *et al.* (2014) concluded that drought stress increased the content of phenolic compounds on different lettuce cultivars and varieties.

High antioxidant values are valuable for human health because antioxidants have potential beneficial effects in protecting against disease (Sen and Chakraborty, 2011). Therefore, less irrigation in lettuce can be more desirable for health body functions.

The results of this study showed that the water use efficiency decreased in the less irrigation conditions because marketable yield of lettuce significantly decreased. However, the mineral content, total phenolic content and antioxidant activity increased with the decrease in irrigation quantities. It was concluded that highly marketable yields in lettuce grown in a semi-arid region with a cool climate under high altitude conditions may be obtained with irrigation applications done considering water depths which equal 100% of evaporated water from a Class A pan. However, more healthy lettuce production may be achieved with irrigation applications done considering the levels of 85 or 70% of evaporated water from a Class A pan.

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