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Full Length Research Paper

The effects of drip line depths and irrigation levels on yield, quality and water use characteristics of lettuce under greenhouse condition

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This study was conducted to investigate the effects of different drip irrigation methods and different irrigation levels on yield, quality and water use characteristics of lettuce (*Lactuca sativa* var. *longifolia* cv. Lital) cultivated in a solar greenhouse from 07 October 2009 to 03 December 2009 in the Eastern Mediterranean region of Turkey. The irrigation methods were consisted of traditional surface drip irrigation (TDI), subsurface drip irrigation at 10 cm drip line depth (SDI_{10}) and subsurface drip irrigation at 20 cm drip line depth (SDI_{20}). At the treatment of irrigation levels, five irrigation treatments (I) were based on adjustment coefficients (0.25, 0.50, 0.75, 1.0 and 1.25) of Class A pan evaporation. For the yield and quality parameters of plant; marketable head weight (yield), number of marketable leaves, leaf area, plant height and diameters, plant dry weight, core diameters and firmness of head, leaf chlorophyll content, total soluble solids (TSS as °Brix), electrical conductivity (EC), pH, total dissolved solids (TDS) and salinity of leaves' juice were determined. The yield and yield components were not affected by the irrigation methods except for core and plant diameters. Irrigation levels had significantly ($p < 0.01$) different effects on yield and yield components except for plant dry weight, plant height and head firmness. The results showed that the highest yield was obtained from $SDI_{10}xI_{100}$ treatment. The water use efficiency (WUE) and the irrigation water use efficiency (IWUE) increased as the irrigation was reduced.

Key words: Subsurface drip irrigation, irrigation level, water use efficiency.

INTRODUCTION

Lettuce is the most popular vegetable with the highest consumption rate and economic importance throughout the world (Coelho et al., 2005). Since the market values of early varieties were high, recently, lettuce was initiated to be grown in tunnels in limited extend (Yazgan et al., 2008).

Water availability is generally the most important natural factor limiting the widespread and development of agriculture in arid and semi-arid regions. Turkey is located in a semi-arid region and there are large areas which are not irrigated due to lack of irrigation water and also agriculture in greenhouse has increased in recent years (Kadayifci et al., 2004). Irrigated agriculture will face significant challenges in the future. Most of the increased food production in the world will depend on irrigation and water use efficiency (WUE) (Najafi and Tabatabaei, 2007). In all agricultural systems, low WUE can occur when soil evaporation is high in relation to crop evapo-transpiration, early growth rate is slow, water application does not correspond to crop demand and when shallow roots are unable to utilize deep water in the profile (Gallardo et al., 1996). New innovations for saving irrigation water and thereby increasing crop water use efficiency (WUE) are especially important in water-scarce regions (Gencoglan

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et al., 2006). Increasing WUE by using improved irrigation techniques is a priority for the agricultural sector (Nalliah et al., 2009). Scheduling water application is very critical to make the most efficient use of drip irrigation system, as excessive irrigation reduces yield, while inadequate irrigation causes water stress and reduces production (Yazgan et al., 2008).

Well-managed subsurface drip irrigation (SDI) systems save water in the irrigation of many agricultural crops because water is directly applied in the root zone without losses due to evaporation or runoff (Suarez-Rey et al., 2006). Also, SDI improves the plants' health, farming operations and management (Elmaloglou and Diamantopoulos, 2009). One of the most commonly discussed aspects of SDI system is installation depth of drip lateral (Patel and Rajput, 2007). In designing subsurface drip irrigation systems for row crops, the dimensions of the wetted volume and the distribution of soil moisture within this volume are two of the main factors in determining installation depth and spacing of drippers to obtain an optimum distribution of water in the crop root zone (Kandelous and Suimunek, 2010). Moreover, determination of quantity and direction of water flow is very important for sustainable land management (Sariyev et al., 2007). While deeper lateral depth leads to the reduction of soil evaporation, a deep installation of emitters can increase water losses due to deep percolation and decrease availability of water for crop roots (Dukes and Scholberg, 2005). Lateral depths have been poorly studied as a treatment variable; hence, little can be said about crop yield differences with lateral depth. Lateral depths vary from 0.02 to 0.70 m, depending upon both the soil and crop (Elmaloglou and Diamantopoulos, 2009).

The effects of subsurface drip irrigation with different drip line depths running in different irrigation levels on yield, yield components and water use characteristics of lettuce are not examined under greenhouse conditions. Therefore, the objectives of this study were to evaluate the effects of different drip irrigation lateral depths and irrigation levels on the yield and yield components of lettuce. Water use characteristics such as evapotranspiration (Et), irrigation water use efficiency (IWUE) and water use efficiency (WUE) of lettuce were also investigated at the experimental conditions.

MATERIALS AND METHODS

Lettuce (*Lactuca sativa* var. *romana* cv. Lital) was cultivated from 07 October 2009 to 03 December 2009 in a polyethylene covered solar greenhouse at the experimental station of the Samandag Vocational College, Mustafa Kemal University, located in the district of Samandag, Hatay, Turkey, with the latitude 36°04' N and the longitude 35°57' E and altitude 3.1 m above sea level.

Samandag has typical Mediterranean climate conditions with hot-dry summers and mild-rainy winters. Climatic data of the experimental area during the experimental period are given in Table 1. The mean temperatures ranged between 16.8 and 26.2°C and the mean relative humidity changed from 53.0 to 59.6% during the experimental period in the greenhouse. The properties of the experimental plot's soil sample from 0 to 60 cm soil depth are given in Table 2. Soil salinity (ECe= 2.7 and 3.2 dS m^{-1}) was greater than the soil salinity threshold level (ECe=1.3 dS m^{-1}) of lettuce. These values indicated that the yield potential of lettuce was about 90% according to Ayers and Westcot (1985).

The irrigation water used in the study was obtained from a well. The irrigation water sampled from the well at the beginning of the study was analyzed and classified by using the standard procedure of Anonymous (1954). According to the results of the analyses, the water was 1.486 dS m^{-1} and had no serious harmful effect on plant growth. Ground water was also observed below 90 cm soil profile.

The experimental design was split plots with three replications. The main plots were the irrigation methods and the sub-plots were irrigation levels derived from the cumulative evaporation in a Class A pan between two irrigation events. In the experiment, three irrigation methods and five different irrigation levels were tested as the treatments. The irrigation method treatments were the traditional surface drip irrigation (TDI), subsurface drip irrigation at 10 cm (SDI_{10}) drip line depth and subsurface drip irrigation at 20 cm (SDI_{20}) drip line depth (Figure 1). The irrigation levels were full irrigation (I_{100}) which corresponded to 100% of the total Class A pan evaporation, 125% of full irrigation (I_{125}; 25% excessive), 75% of full irrigation (I_{75}; 25% deficit), 50% of full irrigation (I_{50}; 50% deficit) and 25% of full irrigation (I_{25}; 75% deficit) treatments.

The plots were 12.0 m long and 1.50 m wide. Each plot had three rows of plants. The plants were transplanted in the greenhouse at a spacing of 0.3 m x 0.3 m on 07 October 2009 (Figure 1). A common recommended fertilization program was followed in the experiment. All the treatment plots received the same amounts of fertilizer which consisted of 100 kg ha^{-1} P_2O_5 (mono potassium phosphate 52% P_2O_5; 34% K_2O), 200 kg ha^{-1} K_2O (potassium sulfate 51% K_2O) and 150 kg ha^{-1} N (ammonium nitrate, 33.5% N). All fertilizers were applied using drip fertigation in three split application.

Firstly, the drip laterals in the SDI plots was buried when the study was established to depths of 10 and 20 cm in the center of two crop lines in each plot. The starter irrigations were applied for subsistence of the crops after the transplanting; the traditional drip lateral lines were installed in all the experimental plots on the soil surface with two drip lines per plot (one lateral between two crop lines) after planting. After the stand establishment, surface drip laterals were removed in all the SDI plots. The drip irrigation laterals were 16 mm in diameter. The drippers were inline type and were placed 0.30 m apart from each other and had 1.32 L h^{-1} flow rate at 65 kPa pressure. The irrigation system has a typical control unit consisted of a pump, fertilizer tank, gravel and disc filters, control valves, pressure gauges and a flow meter. The applied water was controlled by the flow meter.

After stand establishment on the 20 of October 2009, the first irrigation (45 mm) was applied to all the treatment plots using drip irrigation system to stabilize the soil water content in effective root depth. After that, irrigations were started when the readings of the tensiometer placed in 30 cm soil depth on the full irrigation (TDI_{100}) plot approached 20 kPa. The amount of irrigation water was calculated using Equation (1):

$$I=A.Epan.Kcp \quad (1)$$

Where, I is the amount of irrigation water (L), A is the plot area (m^2), Epan is the amount of cumulative evaporation during an irrigation interval (mm) and Kcp is the crop-pan coefficient.

Class A pan is located at the center of the experimental plots in the greenhouse. Daily readings of the Class A pan evaporation was made in the mornings during the study. Soil water contents were measured gravimetrically at 30 cm increments down to 60 cm during the study. Soil water status of the irrigation plots were also

Table 1. Some climatic data of the experimental site (inside and outside of the greenhouse).

Months	Temperature (°C)									Humidity (%)		
	Maximum			Minimum			Mean					
	In	Out	*LT	In	Out	LT	In	Out	LT	In	Out	LT
October	35.3	28.5	37.2	18.9	20.0	6.8	26.2	23.7	21.8	53.0	65.3	69.0
November	29.6	20.3	30.0	12.9	12.9	0.0	20.8	16.0	15.8	55.6	76.6	66.0
December	24.3	16.6	22.6	11.7	11.0	-1.4	16.8	13.6	11.3	59.6	81.2	72.0

*LT, Long term means (1975 to 2007) in outdoors.

Table 2. Some soil characteristics of experimental plots.

Soil depth (cm)	Texture	Field capacity (%)	Wilting point (%)	Bulk density (t m^{-3})	ECe (dS m^{-1})	pH
0-30	Clay-loam	36.35	19.12	1.41	2.7	7.3
30-60	Clay-loam	35.76	19.96	1.55	3.2	7.1

BD, Bulk density, ECe, electrical conductivity of the saturation extract.

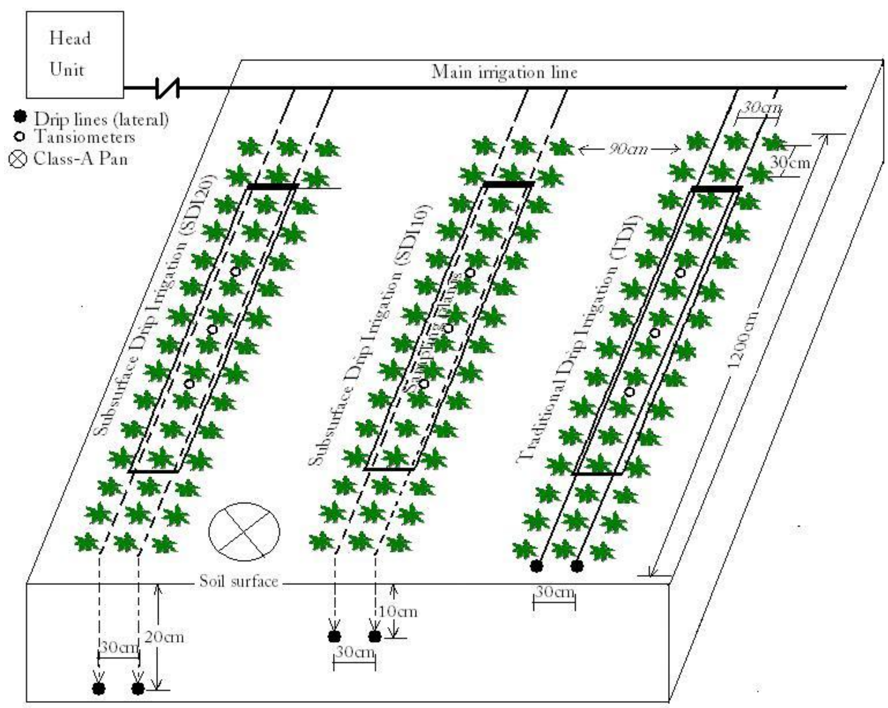

Figure 1. Lettuce plant spacing and drip line placement in the experiment.

monitored by using a tensiometer at 30 cm below the surface of the plots, mid-way between rows of plants. Evapotranspiration (Et) under varying watering regimes was calculated using the soil water balance Equation (James, 1988):

$$Et = I + P \pm \Delta SW - Dp - Rf \quad (2)$$

Where, Et is the seasonal evapotranspiration (mm), I is the irrigation water (mm), P is the precipitation (mm), ΔSW is the change in the soil water storage (mm) in 60 cm soil profile, Dp is the deep percolation (mm) and Rf is the amount of runoff (mm).

Since traditional and subsurface drip irrigations were used in the experimental greenhouse, runoff and precipitation were supposed to be equal to zero. Deep percolation was calculated from the difference between the field capacity moisture level and total soil moisture level at 0.60 m soil depth in the observed period (Kashyap and Panda, 2003). WUE and IWUE were calculated as marketable lettuce weight (yield) divided by seasonal evapotranspiration and seasonal irrigation water applied, respectively (Howell et al., 1990; Kanber et al., 1992).

The mean marketable head weight (yield), number of marketable leaves, plant height, head and core diameter, plant dry weight and firmness of head were determined using standard procedures just before and after the harvest. Dry matter determinations were made by weighing the plant material immediately after harvesting for moisture determination. Dry weights were recorded after oven-drying the plant samples at 70°C for 72 h. Leaf areas (LA) were determined using an electronic planimeter (X-Plan 300C+, Ushikata Mfg. Co., Ltd. Tokyo, Japan). Specific leaf weight (SLW) was calculated as the ratio of leaf dry mass/leaf area and leaf succulence (LS) as the ratio of leaf × (fresh mass-dry mass)/leaf area (Pascale et al., 2005). The total chlorophyll contents were determined by digital chlorophyll meter (SPAD-502, Minolta, Japan). Four plants (totally 12 outer leaves) per replicate were used for chlorophyll measurement at harvest. In order to determine the total soluble solids (TSS) content of lettuce, four plants per treatment were divided longitudinally into two equal parts and one part per plant was sampled, washed with tap and distilled waters. The sampled leaves were macerated in a blender and the content of TSS (°Brix) was measured in the juice of the leaves using a hand refractometer (N.O.W., Nippon Optical Warks Co. model 507-I, Tokyo, Japan). EC (electrical conductivity), pH, TDS and salinity of the juice was measured by digital EC-pH meter (Consort NV., model C533, Belgium).

Data were subjected to statistical analysis using the MSTAT-C software (Michigan State University) and the treatment means were compared by LSD (least significant differences) test at $p < 0.05$ significant level. Graphical illustrations of the data were made by Ms-Office 2007, Excel software.

RESULTS AND DISCUSSION

Irrigation and water use characteristics

In the study, irrigation program was used in three irrigation methods and the amounts of irrigation water were calculated with pre-determined coefficients (0.25, 0.50, 0.75, 1.0 and 1.25) of Class A pan evaporation at the irrigation level treatments. Thus, different irrigation level plots were irrigated with different amounts of water. The first irrigation was applied on 20 October 2009 and the last irrigation was made on 27 November 2009. The irrigation frequency varied between 5 and 8 days according to tensiometer readings. Seven irrigation applications were performed in all the experimental plots according to predetermined irrigation levels. The seasonal irrigation amounts were 75, 151, 226, 301 and 376 mm in treatments I_{25} to I_{125}, respectively (Table 3). Crop seasonal evapotranspiration (Et) values differed with the amounts of irrigation water applied and the irrigation methods. Higher Et values were determined in the TDI method than in the SDI methods. Because of the minimization of evaporative water losses in SDI methods, crop Et values decreased. Similar decreases were reported by Kadayifci et al. (2004) under mulch application for lettuce. The minimum Et values were obtained in the I_{25} irrigation treatments in three irrigation methods in the experiments. The lowest Et at I_{25} treatments could be related to the lack of soil moisture resulting from excessive deficit irrigation strategy. The maximum Et values were 408 mm in TDI x I_{125} treatment, 361 mm in $SDI_{10}xI_{125}$ treatment and 349 mm in SDI_{20} x I_{125} treatment. The Et values increased with the increments of water amount from I_{25} to I_{125} irrigation treatments in three irrigation methods. Similar Et trends were reported earlier for different plants; Kadayifci et al. (2004) for lettuce, Gencoglan et al. (2006) and Sezen et al. (2008) for green bean and Wang et al. (2009) for cucumber plant. The highest Et was 408 mm in TDI x I_{125} treatment in. This result might have resulted from higher evaporative losses of soil water in the TDI method than in SDI methods. Additionally, deep percolations which resulted from excess irrigation amounts were seen in SDI methods at deeper lateral depths. It was shown that the deeper the lateral depth was the higher was the deep percolations among the irrigation methods. There was a significant linear relationship (R^2=0.94 in TDI, R^2=0.96 in SDI_{10} and R^2=0.96 in SDI_{20} treatments) between the irrigation water applied and the crop Et.

The rates of Et were low at the early stages of vegetative growth (from 1 to 15 days after transplanting, DAT), then increased gradually (from 16 to 57 DAT) by the end of the growing season, when crops had reached the maximum number of mature leaves in the experiment. Likewise, Karam et al. (2002) and Bozkurt et al. (2009) demonstrated similar results in their study. There was a significant polynomial relationship (R^2=0.96 in TDI, R^2=0.82 in SDI_{10} and R^2=0.93 in SDI_{20} treatments) between the lettuce yield and the crop Et as shown in Figure 2. Similar polynomial relationship (R^2=0.97 in TDI, R^2=0.86 in SDI_{10} and R^2=0.99 in SDI_{20} treatments) were found between yield and the irrigation water applied (Figure 3). Capra et al. (2008) declared similar polynomial relationship between the field grown lettuce marketable yield and the total water received. Erdem et al. (2005) also declared similar relationship for melon. Lettuce yields under the three irrigation methods increased up to full irrigation (I_{100}) treatments. Similar results for drip irrigated lettuce under greenhouse condition were reported by Yazgan et al. (2008). However, further increases in Et values in connection with increased irrigation water at I_{125} treatment decreased lettuce yield in the three irrigation methods in the experiment.

The terms of WUE and IWUE have commonly been used to clarify water productivity in crop production. In the experiment, WUE's under TDI method ranged from a minimum of 12.4 kg m^{-3} in I_{125} to a maximum of 27.3 kg m^{-3} in I_{25} treatments. IWUE were ranged from a minimum of 13.4 kg m^{-3} in I_{125} to a maximum of 46.3 kg m^{-3} in I_{25} treatments (Table 3). The WUE and the IWUE values obtained in the SDI methods showed similar trends with the TDI method. The highest WUE value in the experiment was 33.6 kg m^{-3} in I_{25} irrigation level under SDI_{10} treatment, whereas the lowest WUE value was 12.4 kg m^{-3} in I_{125} irrigation levels under TDI treatment. Minimum IWUE (11.6 kg m^{-3}) was obtained from the I_{125} treatment in the SDI_{20} method and maximum IWUE (47.9 kg m^{-3}) was obtained from the I_{25} in the SDI_{10} irrigation methods. There was a significant linear relationship (R^2=0.97 in TDI, R^2=0.99 in SDI_{10} and R^2=0.99 in SDI_{20} treatments) between the WUE and the IWUE. The WUE and IWUE increased with decreasing amount of irrigation water in the three irrigation methods. These results are in agreement with the results of Sammis et al. (1988) and Bozkurt

Table 3. Yield, evapotaranspiration (Et), irrigation water (I), water use efficiency (WUE) and irrigation water use efficiency (IWUE) for the different treatments.

Treatment		Yield (kg ha^{-1})	I (mm)	Soil water depletion (mm)	Dp (mm)	Et (mm)	IWUE (kg m^{-3})	WUE (kg m^{-3})
TDI	I_{25}	34707	75	52	-	127	46.3	27.3
	I_{50}	44000	151	50	-	201	29.1	21.9
	I_{75}	49807	226	60	-	286	22.0	17.4
	I_{100}	55100	301	71	-	372	18.3	14.8
	I_{125}	50467	376	32	-	408	13.4	12.4
SDI_{10}	I_{25}	35900	75	32	-	107	47.9	33.6
	I_{50}	42047	151	38	-	189	27.8	22.2
	I_{75}	49513	226	47	-	273	21.9	18.1
	I_{100}	57753	301	42	-	343	19.2	16.8
	I_{125}	48680	376	-	15	361	12.9	13.5
SDI_{20}	I_{25}	33260	75	49	-	124	44.3	26.8
	I_{50}	40067	151	63	-	214	26.5	18.7
	I_{75}	45587	226	81	-	307	20.2	14.8
	I_{100}	47393	301	31	-	332	15.7	14.3
	I_{125}	43673	376	-	27	349	11.6	12.5

Dp, Deep percolation.

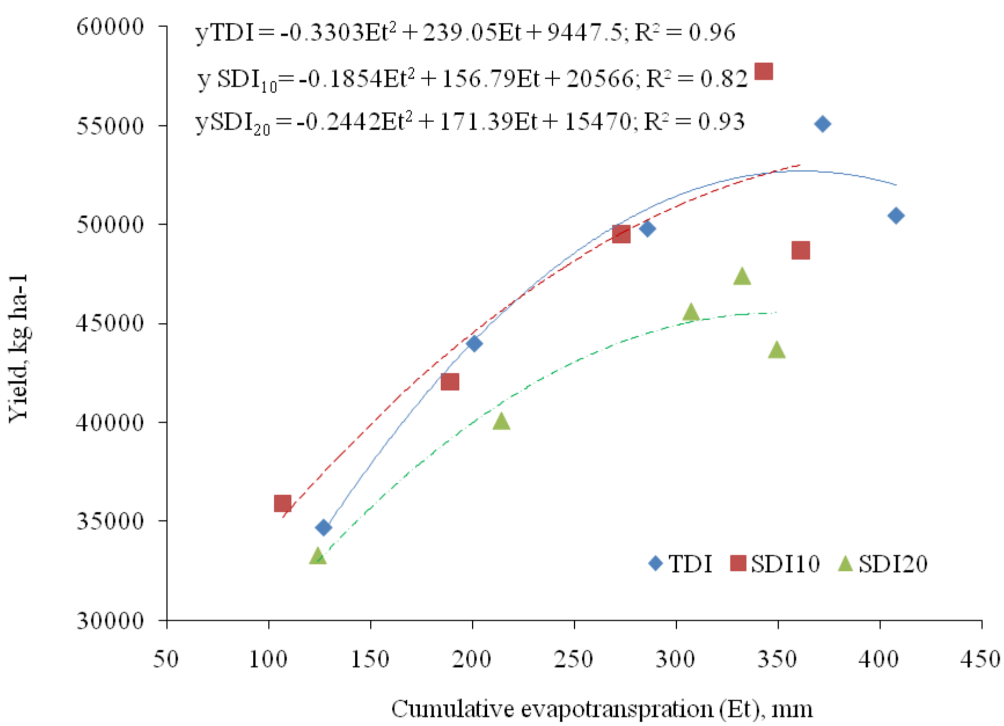

Figure 2. The relationship between lettuce yield and cumulative evapotranspiration under different irrigation methods.

et al. (2009). WUE values were also negatively correlated with lettuce yield (Figure 4). This indicates and confirms that, the water productivity under water shortage condition was higher than the full or excess water applications.

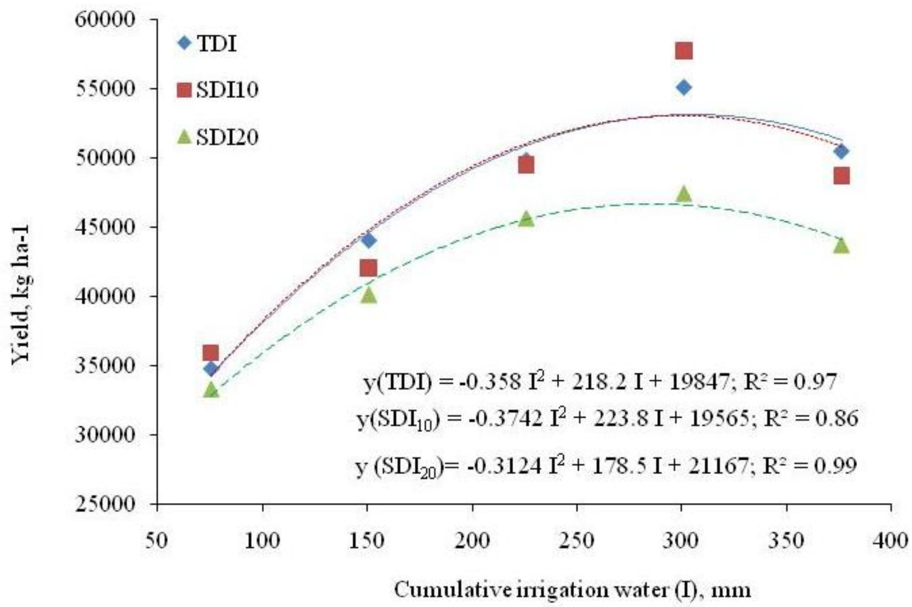

Figure 3. The relationship between lettuce yield and the cumulative irrigation water applied under different irrigation. methods.

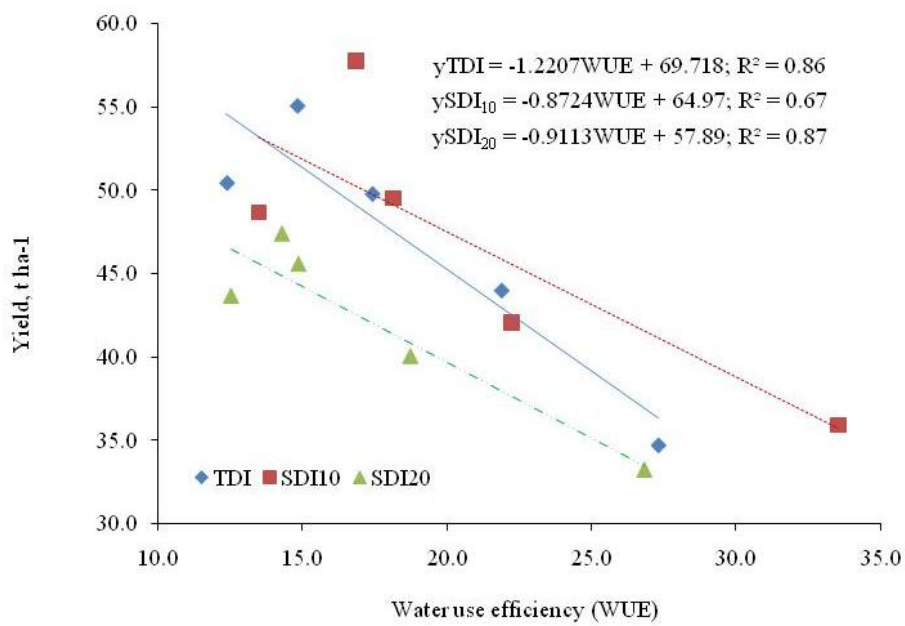

Figure 4. The relationship between lettuce yield and water use efficiency for different irrigation methods.

Yield and quality responses of lettuce

Yield responses of lettuce to the five different irrigation levels under the three irrigation methods were determined in the experiment. Analyses of variance were performed to determine the effects of the irrigation methods and irrigation levels on lettuce yield and yield components (Table 4). Yield and yield components were not affected by irrigation methods except for core and plant diameters. Irrition levels had significantly ($p < 0.01$) different effects on yield and yield components except for plant dry weight, plant height and head firmness. Acar et al. (2008) reported

Table 4. The results of variance analyses for yield and quality components.

Source of variance	df	Yield	Plant height	Plant diameter	Core diameter	Head firmness	Leaf area	Plant DM	SLW	TSS (°Brix)	EC	pH	TDS	Salinity	Chlorophyll	NML	LS
Replication	2	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
Irrigation methods (D)	2	ns	ns	**	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Irrigation levels (I)	4	**	ns	**	**	ns	**	ns	ns	**	ns	ns	ns	ns	ns	**	**
DXI	8	ns	ns	**	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)		5.78	9.86	8.16	10.32	43.74	14.49	28.11	41.19	7.54	16.15	2.45	16.52	17.75	23.84	10.04	15.99

*Significant at $p < 0.05$; **significant at $p < 0.01$; df: degrees of freedom; CV, coefficient of variation; (1) Head firmness on a scale of 1=loose 5=compact; NML, no of marketable leaf; SLW, specific leaf weight; LS, leaf succulence; TSS, total soluble solids; DM, dry matter.

that, different irrigation levels did not significantly affect mean leaf number, head height and head circle. This is in contrast with our results except for head height (plant height). Yazgan et al. (2008) also reported that, the deficit irrigation did not affect the plant height for lettuce. The interaction effects of the irrigation methods and the irrigation levels had no significant effects on yield and yield components except for core and plant diameter at $p < 0.01$ level. Lettuce quality components were not affected by the irrigation methods. Irrigation levels had significant effect on total soluble solids of the leaves and leaf succulence (LS). Interaction effects of irrigation methods and irrigation levels had no significant effects on lettuce quality.

In the irrigation methods, treatment means were separated using LSD ($p < 0.05$) test (Table 5). Irrigation methods had no significant effects on yield and yield parameters. While extremely similar yield values were found in TDI (702.2 g plant^{-1}) and SDI_{10} (701.7 g plant^{-1}) irrigation methods, yield decreases up to 10% were found in SDI_{20} (629.9 g plant^{-1}) irrigation methods. The highest plant height, plant dry weight and number of marketable leaves were obtained from SDI_{10} treatment plots. Similarly, the highest core (16 cm) and plant (31.69 cm) diameter was obtained from SDI_{10} treatment plots. For quality components, the highest electrical conductivity (EC) (7.5), TDS (4.1) and salinity (4.7) of lettuce juice was found in SDI_{20} plots. The highest leaf succulence (LS) (691.1 g H_2O plant^{-1}) was obtained in SDI_{20} plots. There was a significant polynomial relationship (R^2=0.96 in TDI, R^2=0.99 in SDI_{10} and R^2=0.69 in SDI_{20} treatments) between the LS and the Et (Figure 5). The LS value increased with the increasing amount of irrigation water or Et in the three irrigation methods. The irrigation methods did not show any significant effect on TSS contents of the lettuce leaves.

In the irrigation level treatments, the LSD test results showed that the highest yield (801.2 g plant^{-1}) and leaf area (1.1 m^2 plant^{-1}) was obtained from I_{100} treatments (Table 6). The lowest yield (519.3 g plant^{-1}) and leaf area (0.61 m^2 plant^{-1}) was found in I_{25} plots. In I_{125} irrigation plots, yield decreased by 10% (714.1 g plant^{-1}) compared with those of I_{100} plots. This reduction might have been caused by nitrogen losses from the especially deep percolation, volatilization and denitrification processes. It might have also been caused by the better water usage and better soil-water-air combination with higher aeration of the root zone in I_{100} plots. In the 25% water deficit (I_{75}), yield decreased with a reduction of 9.6% from 801.2 g plant^{-1} to 724.5 g plant^{-1}. Similar trends were shown in the change of the leaf areas. Karam et al. (2002) reported that, water deficit produced significant differences in fresh weight of individual heads ($p < 0.05$). The average fresh weight of the well-irrigated plants (I-100 indicated to receive 100% of the soil water depletion) in their report was 757 g, whereas I-80 and I-60 treatments resulted in 14 and 39% reduction in fresh weight, respecttively. Additionally, Acar et al. (2008) also declared that the head weights were 355.17, 340.3 and 338.43 g from S1 (receiving 100% of the soil water depletion), S2 (80%) and S3 (60%)

Table 5. The LSD test results of yield and yield components under different irrigation methods.

Parameter	Treatment			
	TDI	SDI_{10}	SDI_{20}	$LSD_{0.05}$
Yield (g $plant^{-1}$)	702.2	701.7	629.9	ns
Plant height (cm)	33.5	34.0	32.4	ns
Plant diameter(cm)	25.0^c	31.69^a	29.4^b	1.6
Core diameter (cm)	12.6^c	16.0^a	14.8^b	0.8
Head firmness (1-5) [(1)]	2.7	2.5	2.5	ns
Leaf area (m^2 $plant^{-1}$)	0.88	0.87	0.80	ns
Plant dry weight, (g $plant^{-1}$)	13.7	16.1	12.2	ns
Total soluble solids (°Brix)	3.1	3.1	3.1	ns
EC (mS cm^{-1})	7.1	7.3	7.5	ns
pH	6.2	6.2	6.1	ns
Total dissolved solids (TDS)	3.9	3.9	4.1	ns
Salinity (%)	4.4	4.4	4.7	ns
Chlorophyll	25.7	26.5	23.9	ns
Specific leaf weight (SLW)	17.7	17.5	18.0	ns
Leaf succulence (LS)	653.0	660.4	691.1	ns
No of marketable leaf	61.8	70.8	66.3	ns

[+]Means followed by the same letter(s) in the same lines are not significantly different at 0.05 level; ns, non significant; [(1)] Head firmness on a scale of 1=loose and 5=compact.

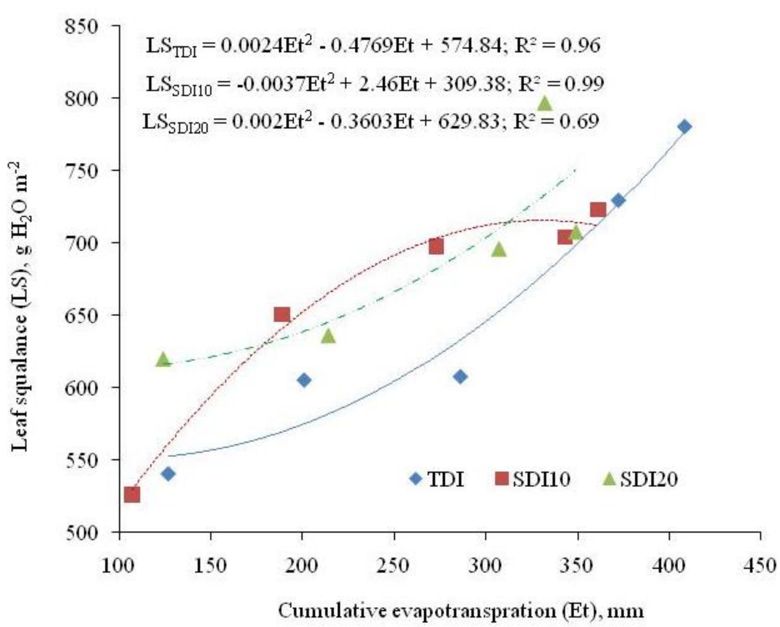

Figure 5. The relationship between leaf squalance and cumulative evapotranspiration for different irrigation methods.

Table 6. Mean comparison (LSD) of irrigation level treatments.

Parameter	Treatment					$LSD_{0.05}$
	I_{25}	I_{50}	I_{75}	I_{100}	I_{125}	
Yield (g plant^{-1})	519.3^{d}	630.6^{c}	724.5^{b}	801.2^{a}	714.1^{b}	38.14
Plant height (cm)	33.8	33.5	32.1	34.6	32.5	ns
Plant diameter (cm)	28.2^{b}	28.0^{b}	24.5^{c}	31.9^{a}	30.9^{a}	2.3
Core diameter (cm)	14.8^{b}	14.6^{b}	14.7^{b}	17.4^{a}	16.7^{a}	1.4
Head firmness (1-5) $^{(1)}$	2.2	2.5	2.6	2.3	2.8	ns
Leaf area (m^2 plant^{-1})	0.61^{d}	0.73^{cd}	0.97^{b}	1.1^{a}	0.8^{c}	0.12
Plant dry weight (g plant^{-1})	14.3	16.2	15.2	12.4	11.9	ns
Total soluble solids (°Brix)	3.2^{ab}	3.3^{a}	3.0^{bc}	3.1^{ab}	2.8^{c}	0.23
EC (mS cm^{-1})	7.4	7.7	7.4	6.5	7.6	ns
pH	6.1	6.2	6.1	6.1	6.2	ns
Total dissolved solids (TDS)	4.06	4.21	4.02	3.55	4.13	ns
Salinity (%)	4.6	4.8	4.6	4.0	4.6	ns
Chlorophyll	21.8	23.0	24.2	28.9	24.4	ns
Specific leaf weight (SLW)	21.1	17.2	18.2	14.4	17.7	ns
Leaf succulence (LS)	562.4^{c}	630.7^{bc}	667.1^{ab}	743.5^{a}	737.1^{a}	103.9
No of marketable leaf	52.0^{d}	63.2^{c}	71.5^{ab}	77.1^{a}	67.6^{bc}	6.5

+Means followed by the same letter(s) in the same column are not significantly different at 0.05 levels; ns, non significant; (1) Head firmness on a scale of 1=loose and 5=compact.

water applications, respectively. The results of this study are in good agreement with the findings reported by Karam et al. (2002). Although, interaction effects of irrigation methods and irrigation levels on yield was not statistically significant, the highest yield (866.3 g plant^{-1}) was obtained from I_{100} irrigation level in SDI_{10} treatment.

The highest core (17.4 and 16.7 cm) and plant (31.9 and 30.9 cm) diameter was obtained in I_{100} and I_{125} treatment plots, respectively. Lowest core and plant diameter was obtained from I_{25} plots. Irrigation levels had no a statistically significant effect on specific leaf weight (SLW) and plant dry weight. The highest plant dry weight was obtained from I_{50} treatment plots. Plant dry weight increased slightly with decreasing irrigation amount. Yazgan et al. (2008) declared that, the significant increases in dry matter were found as parallel to irrigation water deficit. Soundy et al. (2005) reported that, the root dry weights were unaffected by moisture deficit, however, shoot dry weight and leaf N content increased with increasing moisture deficit in the media. As reported earlier by Gallardo et al. (1996), the decreased water supply had a greater effect on the fresh weight than on the dry weight. Irrigation level treatments had a significant effect on total marketable leaf number and leaf area. The number of marketable leaves reached at harvest a total of 77 on the I_{100} treatment, while leaf area per plant reached 1.1 m^2 on the same treatment. As reported by Karam et al. (2002), the effect of water deficit on lettuce growth was the reduction of leaf area as a consequence of leaf number reduction.

In quality parameters, different irrigation levels had significant effects on the TSS content of leaves. The highest (3.3 °Brix) TSS content was found in I_{50} treatment plots. Acar et al. (2008) reported that, the drip irrigation at S1 (100% Class A pan replacement) treatment gave the highest TSS as 3.32 °Brix for lettuce. In our study, the TSS content in I_{100} irrigation level was 3.1°Brix. Irrigation level treatment did not show any significant effect on other quality parameters.

Conclusions

The results of this study indicated that, different irrigation levels had significant effects on the majority of yield components. Irrigation scheduling based on a 1.0 crop-pan coefficient is recommended for traditional and subsurface drip irrigations. Under the severe water scarcity conditions, it may be recommended that I_{50} treatment was the most suitable as a water application level for lettuce irrigation by TDI or SDI_{10} treatments under the unheated greenhouse conditions. Yield and other yield components were not affected statistically by drip line depths. Since there were only minor differences between yields of lettuce obtained from TDI and SDI_{10} irrigation methods, TDI emerged as a more suitable irrigation method and might be recommended to avoid the higher labor and technical skills. However, SDI_{10} drip line depth treatment had the highest yield and higher IWUE under full (I_{100}) irrigation. Therefore, SDI_{10} x I_{100} treatment was an optimum irrigation schedule for the lettuce plants grown in the unheated plastic greenhouse under the Mediterranean climatic condition.

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