Instituto Nacional de Investigación y Tecnología Agraria y Alimentación (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2008 6(4), 714-719
ISSN: 1695-971-X

Short communication. Effect of deficit irrigation on curly lettuce grown under semiarid conditions

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Abstract

Field experiments were conducted to characterize the effects of deficit irrigation on curly lettuce (*Lactuca sativa* var. Crispa cv. Bohemia) evapotranspiration, water use efficiency, marketable yield, yield components and mineral contents. The experiments were performed under semiarid climatic conditions in Erzurum province (east of Turkey) in the summer periods of 2005 and 2006. Irrigation water levels were selected to be 100% of usable soil water in full irrigation treatment (control) (T-100) and 80%, 60%, 40% and 20% of usable soil water in deficit irrigation treatments (T-80, T-60, T-40 and T-20, respectively). Average seasonal evapotranspiration was 232 mm in T-100 and 121 mm in T-20. Average marketable yield was 39.49 Mg ha^{-1} in T-100 and 14.57 Mg ha^{-1} in T-20. A linear relationship (y=0.23x-13.97; R^2= 0.94) was found between seasonal evapotranspiration (x) and marketable plant yield (y). According to the regression equation, the yield response factor (k_y) was found to be 1.39, and the coefficient of determination 0.91. Average water use efficiency was 168.88 kg ha^{-1} mm^{-1} in T-100 and 117.39 kg ha^{-1} mm^{-1} in T-20. The lowest plant length, width, steam diameter, leaf number, macro and micro element content values were obtained for T-20 in both years.

Additional key words: curly lettuce, deficit irrigation, evapotranspiration, macro and micro elements, yield components.

Resumen

Comunicación corta. Efecto del riego deficitario en la lechuga rizada bajo condiciones de clima semiárido

Se estudiaron los efectos del riego deficitario sobre la evapotranspiración, eficiencia del uso del agua, producción comercial y los contenidos minerales de la planta de lechuga rizada (*Lactuca sativa* var. Crispa cv. Bohemia). Los experimentos se realizaron bajo condiciones climáticas semiáridas en la provincia de Erzurum (este de Turquía), durante 2005 y 2006. Los niveles de agua aplicados fueron el 100% del agua útil del suelo en el tratamiento control (T-100), y el 80%, 60%, 40% y 20% de agua útil del suelo en los tratamientos de riego deficitario (T-80, T-60, T-40 y T-20, respectivamente). La evapotranspiración estacional media fue de 232 mm en el tratamiento T-100 y 121 mm en el tratamiento T-20. La producción comercial media fue de 39,49 Mg ha^{-1} en el tratamiento T-100 y 14,57 Mg ha^{-1} en el T-20. Se encontró una relación lineal (y = 0,23x-13,97; R^2 = 0,94) entre la evapotranspiración estacional (x) y la producción comercial de la planta (y). Según la ecuación de regresión, el factor de la respuesta de la producción (k_y) resultó ser 1,39 y el coeficiente de la determinación 0,91. La eficiencia media del uso del agua fue 168,88 kg ha^{-1} mm^{-1} en el tratamiento T-100 y 117,39 kg ha^{-1} mm^{-1} en el tratamiento T-20. Los valores más bajos de longitud, anchura, diámetro del tronco, número de hoja, macro y microelementos se obtuvieron en el tratamiento T-20 en ambos años.

Palabras clave adicionales: componentes del rendimiento, evapotranspiración, lechuga rizada, macro y microelementos, riego deficitario.

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Received: 17-09-07. Accepted: 02-07-08.

Abbreviations used: EC (electrical conductivity), ET (evapotranspiration), IWUE (irrigation water use efficiency), LSD (least significant difference), ns (non-significant), SAR (sodium adsorption ratio), SD (standard deviation), WUE (water-use efficiency).

Serious water shortage is one of the main problems in arid and semiarid regions. The great challenge for coming decades in these regions will be focusing on increase food production by using less water (FAO, 2002). Therefore, studies are needed to increase the efficiency of the water use that is available. One approach is the development of new irrigation scheduling techniques such as deficit irrigation (Bekele and Tilahun, 2007). The potential benefits of deficit irrigation derive from increased irrigation efficiency and reduced irrigation and water opportunity costs (English and Raja, 1996). Yield reduction in deficit irrigation is minimized through the value of the conserved water (English, 1990).

Turkey has favorable agro-ecological conditions for vegetable growth, and is one of the most important vegetable producers in the world. According to 2006 statistics, Turkey has 24×10^6 Mg total vegetable production. However, in Turkey most of the vegetable areas have semiarid conditions. Leaf edible vegetables, including lettuce, are largely produced in Turkey. The total production of curly lettuce (*Lactuca sativa* var. Crispa) and regular lettuce (*Lactuca sativa* var. Longifolia) in Turkey is 151,164 and 239,495 Mg, respectively (Turkstat, 2007).

Among horticultural crops, vegetables need frequent irrigation for better growth and yield. The seasonal water consumption of lettuce plants can be as low as 100 mm at the beginning of the season, but increases to over 400 mm in the peak of the season (Sammis *et al.*, 1988; Gallardo *et al.*, 1996; Karam *et al.*, 2002; Kirnak *et al.*, 2002; Kadayifci *et al.*, 2004; Oliveira *et al.*, 2005).

The objectives of this study were: (1) to examine the effects of different water deficits on evapotranspiration, water-use efficiency (WUE), marketable yield, yield components and mineral element content of curly lettuce in semiarid climate conditions and (2) to determine water deficit ratios that can be used in semiarid regions where irrigation water supplies are limited.

Field experiments were conducted at the Agricultural Research Station of Atatürk University located in Erzurum-Turkey (altitude of 1,835 m) during the summer periods of 2005 and 2006. During the growing period, total precipitation and total class A pan evaporation values were 63.4 mm and 388.7 mm respectively in 2005 (4 July-29 August) and 48.9 mm and 448 mm in 2006 (28 June-24 August).

Soil samples were taken from 0-30 and 30-60 cm soil depth in 2005 and 2006 before planting. Soil samples were air-dried, crushed, and passed through a 2-mm sieve prior to physical and chemical analysis. Texture was characterized by 35.5% sand, 34.7% silt, and 29.8% clay. The available water content was 155.2 mm m^{-1} and 158.9 mm m^{-1} in 2005 and 2006, respectively. The soil was sampled at depths of 0-30 and 30-60 cm in both experimental years. The chemical analysis of the samples yielded the following average results: 1.0-1.15% for $CaCO_3$, 0.90-1.50% for organic matter, 1.05-1.21 dS m^{-1} for electrical conductivity, 7.05-7.32 for pH, and 29-32 $cmol_c$ kg^{-1} for cation exchangeable capacity.

The experimental design was based on randomized plots (a total of 15 plots) with three replications. Each experimental plot had an area of 3 x 3 m, and was enclosed by dikes and leveled to zero slope. There was a 2.0 m space between plots in order to minimize water movement among treatments. Plots were fertilized before seedling. Nitrogen, phosphorus and potassium were applied as a basal fertilizer at the rate of 180 N kg ha^{-1} (20.5% N ammonium sulphate), 120 kg P_2O_5 ha^{-1} (48% P_2O_5 triple superphosphate), and 150 kg K_2O ha^{-1} (50% K_2O potassium sulphate), respectively. *Lactuca sativa* var. Crispa cv. Bohemia was used as plant material, and planted on 4 July 2005 and on 28 June 2006. The seedling distances were 50 x 50 cm between and within rows. So, 36 curly lettuce plants were cultivated in each plot. Plant samples were taken from 16 central plants to avoid edge effects. The experiment started with the soil water of all plots at field capacity. The crop was weeded manually with a hoe as often as required. No pesticide was applied.

In the study, five irrigation treatments differing in irrigation rate were evaluated. Irrigation was applied when approximately 30% of the available soil moisture was consumed in the effective root depth (30 cm) at the control treatment (called T-100). The measured soil water at the T-100 treatment was used to initiate irrigation during the growing season. In treatments T-80, T-60, T-40 and T-20 irrigations were applied at the rates of 80, 60, 40 and 20% of the control treatment (T-100) on the same day, respectively.

Underground water with an electrical conductivity (EC) of 0.28 dS m^{-1}, sodium adsorption ratio (SAR) of 0.40, and pH of 7.4 was used for level-basin irrigation. Water applied to each experimental plot was measured using a volumetric flow meter connected to an irrigation pipe. Irrigations started on 14 July in 2005 and on 11 July in 2006.

Plants were harvested on 29 August 2005 and on 24 August 2006, respectively. At harvest time, plant length, width, stem diameter, leaf number and marketable yield were determined. The harvested tissues were oven-dried at 68°C for 48 h and ground. Total N was determined by using the micro-Kjeldahl method. Macro (P, K, Na, Ca, and Mg), and micro elements (Fe, Mn, Zn, Cu, Ni, Pb, and Cd) were determined after wet digestion of dried and ground sub-samples in a HNO_3-$HClO_4$ acid mixture (4:1 v/v). In the diluted digests, P was measured spectrophotometrically by the indophenol-blue method and after reaction with ascorbic acid. Potassium, Na, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Pb, and Cd analysis were determined by atomic absorption spectrometry (Perkin Elmer 3690) (AOAC, 1990).

Evapotranspiration was calculated under varying irrigation regimes using the soil water balance equation (Allen *et al.*, 1998) as,

$$ET = I + P + C_r - D_w - R_f \pm \Delta S$$

where ET is the evapotranspiration, I the amount of irrigation water applied, P the amount of rainfall, C_r the amount of capillary rise, D_w the amount of drainage water, R_f the amount of runoff, and ΔS the change in the soil moisture content. Deep percolation from irrigation water was assumed to be negligible because the amount of irrigation water did not increase above the field capacity. Roots of the curly lettuce plant were not influenced by a water table. The amount of capillary rise from the soil layer of 30-60 cm to 0-30 cm was determined according to the changes in soil water of 30-60 cm soil layer. There was no observed runoff during the experiment.

The relationship between relative evapotranspiration reduction $(1-\frac{ET_a}{ET_m})$ and relative yield reduction $(1-\frac{Y_a}{Y_m})$ was determined using the method given by Doorenbos and Kassam (1979). The equations are as follows:

$$1-\frac{Y_a}{Y_m} = k_y\,(1-\frac{ET_a}{ET_m})$$

or

$$Y_d = k_y\, ET_d$$

Where Y_a is the actual harvested yield, Y_m the maximum harvested yield, k_y the yield response factor, ET_a the actual evapotranspiration, ET_m the maximum evapotranspiration, Y_d the relative yield reduction, and ET_d the relative evapotranspiration reduction.

Water use efficiency (WUE) was calculated as yield (kg ha^{-1}) divided by evapotranspiration (mm). Irrigation water use efficiency (IWUE) was determined as yield (kg ha^{-1}) per unit irrigation water applied (mm) (Howell *et al.*, 1990).

Regression was used to evaluate evapotranspiration-yield relationships using seasonal evapotranspiration and marketable yield data obtained from curly lettuce experiments. Analysis of variance (ANOVA) was conducted to evaluate the effects of the treatments on the marketable yield, WUE, plant length, width, stem diameter, leaf number, and macro and micro element contents. Statistical analyses were made using MINITAB statistical package (release 11.12, 1996; Minitab Inc.). Significant means were compared with Duncan multiple range test method by using MSTAT-C package software (MSTAT-C, 1988).

The total number of irrigations, irrigation water amounts applied and seasonal evapotranspiration values of curly lettuce for the experimental years are presented in Table 1. The total number of irrigations, the applied irrigation water and the evapotranspiration in 2005 growing period were lower than in 2006. This may be attributed to differences in climatic conditions. In the control treatment, T-100, the amount of total irrigation water applied and seasonal evapotranspiration values were 139.7 mm and 209.9 mm in 2005 and 214.5 mm and 254.6 mm in 2006, respectively. The decrease in seasonal evapotranspiration by the increasing water deficit was similar in both study years. The seasonal evapotranspiration in T-20 was 50.8% and 53.1% of that in T-100, for 2005 and 2006, respectively. In Arizona, Oliveira *et al.* (2005) reported a 117 mm average water use for sub-surface drip irrigated head lettuce from emergence to harvest. Kadayifci *et al*. (2004) determined evapotranspiration of lettuce as 285 mm for full irrigation and as 43 mm for a non-irrigated treatment under greenhouse conditions. Karam *et al.* (2002) found that the evapotranspiration of lettuce varied between 413 mm (irrigated at 100% of ET_c) and 337 mm (irrigated at 60% of ET_c), depending on irrigation regimes for a growing cycle of 70 days in Bekaa Valley (Lebanon). In California, Gallardo *et al*. (1996) reported that for well-watered sprinkler-irrigated lettuce, crop evapotranspiration between thinning and harvest (28-63 days after planting) was 153 mm. Sammis *et al.* (1988) reported a seasonal evapotranspiration of lettuce of 205 mm for the highest marketable yield in Hawaii.

As shown in Table 1, data obtained from the two-year study showed that curly lettuce marketable yield was

Table 1. Total number of irrigations, amount of irrigation water and evapotranspiration (ET) for curly lettuce in the years 2005 and 2006

Year	Treatment	Number of irrigations	Irrigation water applied (mm)	Water conservation (%)	ET (mm)	Relative ET (%)	Marketable yield (Mg ha^{-1})	Relative yield (%)
2005	T-100	10	139.7	0	209.9	100.0	33.48 a**	100.0
	T-80	10	111.8	20	181.4	86.4	26.62 ab	79.5
	T-60	10	83.8	40	154.1	73.4	20.57 bc	61.4
	T-40	10	55.9	60	135.5	64.6	12.88 cd	38.5
	T-20	10	27.9	80	106.7	50.8	9.50 d	28.4
2006	T-100	15	214.5	0	254.6	100.0	45.49 a**	100.0
	T-80	15	171.6	20	223.7	87.9	32.64 b	71.8
	T-60	15	128.7	40	190.2	74.7	30.54 b	67.1
	T-40	15	85.8	60	164.8	64.7	27.27 bc	60.0
	T-20	15	42.9	80	135.1	53.1	19.64 c	43.2

** Different letters indicate significant differences at P < 0.01 using Duncan's multiple range test.

significantly (P <0.01) affected by irrigation treatments, and the highest marketable yield was obtained in T-100. When compared to T-100, the decrease in marketable yield in T-20 was 71.6% in 2005 and as 56.8% in 2006. The reason for this difference could be that more water was used by the crop in the second year (Table 1). Rolbiecki and Rolbiecki (2007) reported that irrigation significantly increased marketable yield of lettuce. Kirnak *et al.* (2002) found that a 75% water deficit decreased lettuce yield by approximately 50% in greenhouse conditions. Karam *et al.* (2002) indicated that a 18.4% water deficit reduced lettuce final fresh weight by 30%.

The relationships between seasonal evapotranspiration (mm) and marketable yield (Mg ha^{-1}) were evaluated for 2005, 2006 and 2005-2006. The relationship between seasonal evapotranspiration (x) and marketable yield (y) was linear (P<0.01). The regression equation was determined as $y = 0.24x - 17.66$ for 2005, $y = 0.19x - 6.05$ for 2006 and $y = 0.23x - 13.97$ for 2005-2006. The coefficients of determination (R^2) were 0.98, 0.92 and 0.94, respectively. The linear relation of lettuce yield to water use is in agreement with previous studies (Sammis *et al.*, 1988; Gallardo *et al.*, 1996; Kirnak *et al.*, 2002).

The yield response factor (k_y) was determined for 2005, 2006 and 2005-2006. Relative yield (Y_d) and relative evapotranspiration (ET_d) presented in Table 1 were used to determine the relative yield reduction ($1-Y_d$) and relative evapotranspiration reduction ($1-ET_d$). The resulting k_y values were 1.53 and 1.24 in 2005 and 2006, respectively. According to the regression equation, k_y was 1.39 when both experimental years were considered (R^2 = 0.91). According to Doorenbos and Kassam (1979) k_y can be higher than 1 for vegetables. Sammis *et al.* (1988) determined k_y for drip irrigated lettuce as 1.07. The k_y for lettuce grown under greenhouse conditions was obtained by Kirnak *et al.* (2002) as 0.88 and by Kadayifci *et al.* (2004) as 0.89. Different yield response factor values could be explained by variations in climate, evapotranspiration, soil properties and irrigation practices (Doorenbos and Kassam, 1979).

WUE and IWUE are presented in Table 2. IWUE was higher than the WUE because the amount of irrigation water was lower than evapotranspiration (Table 1). In both years WUE was highest in T-100, but IWUE was highest in T-20. WUE and IWUE in 2006 were higher than in 2005 since the marketable yield in 2006 was higher than in 2005 (Table 1). The values of WUE and IWUE obtained in this work are similar to those reported in previous investigations. Kadayifci *et al.* (2004) found that WUE and IWUE were highest in the full irrigated treatment. Kirnak *et al.* (2002) reported that WUE and IWUE increased with a decrease in irrigation water, and the increase in IWUE was higher than in WUE.

According to Table 2, the highest plant length, width, stem diameter, and number of leaves were obtained from T-100 in both years, whereas these values were the lowest in T-20. Water deficit with 80% decreased significantly

Table 2. Water use efficiency (WUE), irrigation water use efficiency (IWUE), length, width, stem diameter and leaf number values (mean ± SD) of curly lettuce in the growing periods of 2005 and 2006

Year	Treatment	WUE (kg ha^{-1} mm^{-1})	IWUE (kg ha^{-1} mm^{-1})	Length (cm)	Width (cm)	Stem diameter (cm)	Leaf number (cm)
2005	T-100	159.22±19.90	239.63±35.52	29.17±1.11	39.66±1.76	3.73±0.52	57.83±4.75
	T-80	146.28±16.75	238.22±38.18	28.17±2.07	39.00±2.64	3.13±0.31	55.83±5.10
	T-60	132.58±13.88	245.41±49.13	26.00±1.78	34.92±1.51	2.73±0.27	55.16±4.24
	T-40	94.67±9.66	230.43±34.84	20.83±1.09	20.92±1.62	2.46±0.28	53.83±3.85
	T-20	88.64±10.94	340.01±58.67	19.42±0.35	27.83±2.04	1.97±0.16	50.17±4.55
LSD $_{(P<0.05)}$		26.77	80.50	1.89	1.47	0.28	5.40
2006	T-100	178.53±6.48	212.07±14.76	27.91±2.23	44.08±1.84	3.93±0.44	58.66±4.35
	T-80	145.96±4.33	190.23±2.09	25.75±2.41	38.91±2.62	3.71±0.55	54.33±4.80
	T-60	159.81±14.67	237.27±40.79	26.58±2.06	38.16±1.58	3.23±0.26	54.33±5.61
	T-40	165.41±3.07	317.87±16.16	20.83±0.98	28.75±2.42	2.80±0.32	53.16±5.25
	T-20	146.14±7.14	457.73±57.00	19.58±1.36	25.58±1.18	2.58±0.28	53.16±4.23
LSD $_{(P<0.05)}$		14.92	59.76	2.65	4.05	0.54	ns[1]

[1] ns: non-significant

(P<0.05) on plant length, width and stem diameter in the both years when compared to T-100. Our results are in agreement with previous findings. Kirnak *et al.* (2002) reported that lettuce canopy diameter and plant height increased significantly (P<0.05) with increasing irrigation water applied and evapotranspiration. Karam *et al.* (2002) found that water deficit reduced leaf number.

The plant macro (N, P, K, Ca, and Mg) and micro element (Fe, Mn, Zn, Cu, Pb, Ni, and Cd) contents of curly lettuce for the experimental years are presented in Table 3. The water deficit treatments significantly (P<0.05) affected the macro and micro element contents of curly lettuce in both years. Macro and micro element contents decreased with increasing water deficit ratio. The T-20 had the lowest macro and micro element contents. The decreases can be explained by a decrease in plant water uptake. Water and nutrients exist together in close association because plant-available nutrient ions are dissol-

Table 3. Macro (N,P,K, Ca, and Mg) and micro element (Fe, Mn, Zn, Cu, Pb, Ni, and Cd) contents values (mean ± SD) of curly lettuce in the growing periods of 2005 and 2006

Year	Treatment	Macro elements (g 100 g dw^{-1})			Macro elements (mg kg^{-1}dw^{-1})		Micro elements (mg kg^{-1}dw^{-1})						
		N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	Pb	Ni	Cd
2005	T-100	3.68±0.32	0.65±0.11	4.32±1.22	6517±188	746.3±42	237.0±7.3	78.0±2.4	46.0±2.1	57.3±3.4	0.16±0.07	0.27±0.09	1.00±0.09
	T-80	2.85±0.26	0.52±0.13	3.18±0.92	5833±165	627.0±48	187.3±8.7	62.7±2.6	36.0±2.5	38.0±3.6	0.12±0.05	0.24±0.10	0.88±0.13
	T-60	2.50±0.38	0.44±0.10	3.15±1.25	3833±192	402.7±55	134.7±7.1	46.0±1.9	35.3±3.2	26.7±3.9	0.11±0.05	0.23±0.08	0.75±0.17
	T-40	2.09±0.21	0.34±0.13	3.03±1.14	3017±167	309.7±39	133.7±6.3	33.7±3.1	34.7±2.8	18.3±2.8	0.11±0.03	0.19±0.10	0.69±0.15
	T-20	1.93±0.29	0.28±0.09	2.82±1.18	2917±147	299.0±44	124.0±5.1	29.3±2.6	31.3±2.1	12.0±3.2	0.09±0.03	0.19±0.06	0.68±0.10
LSD $_{(P<0.05)}$		0.09	0.06	0.22	711	72.3	8.8	4.4	5.4	5.0	0.02	0.03	0.14
2006	T-100	4.16±0.32	0.73±0.13	4.05±1.17	5042±225	683.3±56	231.3±6.3	73.0±3.2	61.7±2.6	45.7±3.7	0.18±0.05	0.40±0.10	1.06±0.15
	T-80	3.46±0.25	0.55±0.14	3.95±1.23	4778±195	583.3±59	177.0±7.2	63.3±3.6	52.3±2.3	35.0±3.6	0.17±0.06	0.34±0.07	0.83±0.13
	T-60	3.12±0.22	0.49±0.10	3.34±1.19	4060±143	388.3±46	122.3±6.4	44.0±4.1	44.3±3.3	26.0±3.2	0.14±0.03	0.25±0.09	0.77±0.16
	T-40	2.78±0.29	0.48±0.15	3.11±1.24	3504±208	383.3±53	119.0±5.6	35.7±3.3	31.0±2.8	20.0±3.5	0.13±0.02	0.23±0.05	0.77±0.10
	T-20	2.65±0.24	0.41±0.12	2.92±1.05	3343±194	381.7±49	116.7±4.9	34.3±3.9	23.6±2.5	14.7±2.8	0.08±0.02	0.18±0.05	0.63±0.08
LSD $_{(P<0.05)}$		0.15	0.08	0.38	200	12.6	6.0	5.7	4.3	3.5	0.09	0.08	0.11

ved in the soil solution and nutrient uptake by plants depend on water flow through the soil-root-shoot pathway. Leaf transpiration generates the tension necessary for the roots to absorb the essential solution, but in a drying soil, uptake of water and nutrients becomes progressively more difficult for plants. Low water potentials in the root environment decrease ion uptake and transport to shoots. In soil, smaller uptake may result both from impairment of absorption processes in the root and from decreased mobility of ions and water in the soil (Pitman, 1981; Marschner, 1995; Steven and Richards, 1996; Kirnak *et al.,* 2001; Mengel *et al.,* 2001).

The T-100 treatment (full irrigation) should be used for curly lettuce grown in semiarid regions under no water shortage. The T-60 treatment (irrigation applied at the rate of 60%) could be used for curly lettuce grown in semiarid regions where irrigation water supplies are limited. Under this condition, 40% of water conservation was obtained even though there was a 35.8% yield loss for curly lettuce, based on the average of two years.

Acknowledgements

Authors thank to Agriculture Research Centre of Atatürk University for providing research area.

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