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# Deficit irrigation effects on lettuce (*Lactuca sativa* var. Olenka) yield in unheated greenhouse condition

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## Abstract
This study was conducted to determine effect of deficit irrigation on yield for lettuce grown under unheated greenhouse condition. The research was carried out at the Agricultural Research Station of Yenişehir High School of Uludag University in Bursa, Turkey, in 2007. In the study, water was applied to lettuce as 100, 75, 50, 25 and 0% (as control) of evaporation from a Class A Pan corresponding to 2 day irrigation frequency. Irrigation water applied to crops ranged between 51.4 and 484.5 mm, and water consumption ranged between 78 and 511 mm. There were significant differences between treatments in yield, plant height, head diameter, dry matter and mean leaf number. The highest yields were 15.10 and 12.05 t ha$^{-1}$ for the $K1_{cp}$ and $K2_{cp}$ treatments, respectively. Crop yield response factor ($k_y$) was found as 1.096. The highest values for water use efficiency (WUE) and irrigation water use efficiency (IWUE) were found to be 2.96 and 2.70 kg mm$^{-1}$ for the $K2_{cp}$ treatment. Under the conditions that water resources are scarce, it can be recommended that $K2_{cp}$ treatment is most suitable as a water application level for lettuce irrigation by drip irrigation under unheated greenhouse condition.

***Key words:*** Lettuce, deficit irrigation, irrigation water use efficiency.

## Introduction

Greenhouse cultivation, also known as protected cultivation, is one of the farming systems widely used to provide and maintain a controlled environment suitable for optimum crop production leading to maximum profits. This includes creating an environment suitable for working efficiency as well as for better crop growth [1]. Greenhouse cultivation is a steadily growing agricultural sector all over the world [2, 3]. The type of structure primarily used in Turkey is the so-called Mediterranean greenhouse; low-cost, unheated plastic-covered structures and with soil-grown crops.

Lettuce which is one of the most important winter vegetable crops is mostly produced at outdoor. Since the market values of early varieties are high, lettuce is initiated to be grown in tunnels in limited extend recently. When the crop water requirements cannot be met with natural rainfall in greenhouse production, irrigation is major input. Irrigation scheduling involves preventing the soil water deficit from falling below some threshold level for a particular crop and soil condition. This may involve estimating the earliest date to permit efficient irrigation or the latest date to avoid the detrimental effects of water stress on the crop [4]. 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. The optimal use of irrigation can be characterized as the rooting area, and at the same time, avoiding the leaching of nutrients into deeper soil leyers [5]. High frequency water management by drip irrigation minimizes soil as a storage reservoir for water, provides at least daily requirements of water to a portion of the root zone of each plant and maintains a high soil matric potential in the rhizosphere to reduce plant water stress. On the other hand, the intensity of the operation requires that the water supply is kept at the optimum to maximize returns to the farmer.

A widely adopted method for estimating crop consumptive water use (CWU) is the evaporation pan method, which relates evaporation from a Class A evaporation pan to CWU. These two quantities are related by what is called the crop coefficient *K*. Irrigation scheduling based on the crop coefficient *K* is one of the simplest methods where no sophisticated instrument is required. Precise values for *K* are often difficult to establish, given regional and site-specification, soil characteristics, crop physiology and cultural practices. Any recommended value of *K* for regional irrigation scheduling program must be high enough to prevent water stress arising from emergencies and specialized local situations, while remaining low enough for efficient water management [6].

Based on the US Weather Bureau Class A pan evaporation, many studies have been completed on the irrigation of broccoli, carrot, rape cabbage [7], cucumber [8, 9], tomato [10] and potato [11, 12]. Several studies have been performed to investigate the influence of different irrigation levels on lettuce growth and yield [13-15]. The aim of this study was to evaluate the response of drip-irrigated lettuce grown in unheated greenhouse condition to regulated water deficit. The experimental plots were subjected to different irrigation treatments based on adjustment coefficients of Class A pan evaporation and two days irrigation intervals. Then, the effects of irrigation applications on yield and quality were assessed.

## Materials and Methods

Field experiments were carried out under unheated greenhouse condition in Yenişehir-Bursa (40°15'09"N latitude, 29°38'43"E longitude and altitude of 1225 m above mean sea level). A high tunnel with the size of 8 m x 40 m using plastic coverage placed in north-south direction was use for the experiment. Summers are hot and dry; winters are cold and rainy in the region. Annual mean rainfall and temperature are 482.9 mm and 13.6°C, respectively. Average minimum temperature is 3.6°C in December; maximum temperature is 23.3°C in August [16]. The soil of the experimental plot can be classified as sandy loam and the soil pH was 7.99-8.04. Some physical and chemical soil properties are given in Table 1.

Fertilization was 36.5 kg ha$^{-1}$ N and $K_2O$ (15% N and 45% $K_2O$) applied as granular fertilizer prior to sowing and a further N 4.6 kg ha$^{-1}$ added as urea when the plants were 10 cm in height. The experiment areas were sprayed with Captan and Endosulfan for control diseases.

The seed were sown in small pot 15 March 2007 and seedlings were transplanted to the plots (2 April 2007) when the plants showed four to five permanent leaves. The plants were grown 0.50 m apart between the rows with 0.25 m spacing in each row. Each plot contained 80 plants. In order to prevent the water in any one plot from affecting its neighboring plots, only the 15 plants of middle row were harvested. Plant weight (g), head diameter (cm) (two repetition in both east-west and north-south directions) and plant height (cm) were measured by caliper rule and calculated as the average of measured values. All of plant leaves were accepted marketable. The average leaf number per plant was calculated by counting the leaves, and the dry matter amount was found after drying at 85°C in 48 hours.

The layout of the experiment was a completely randomized block design with three replications for each of the five irrigation treatments tested. However, replications have been distributed to the random blocks in such a way that following same range in three blocks not to disturb the existing irrigation system. Irrigation treatments consisted of five different plant-pan coefficients ($K1_{cp}$:1.00, $K2_{cp}$:0.75, $K3_{cp}$:0.50, $K4_{cp}$:0.25, $K5_{cp}$:0.00-control). Pan evaporation method was used for calculation of applied water amount (Eq.1) [17].

$$IW = E_{pan}\, x\, K_{cp} \qquad (1)$$

where $IW$ is the amount of applied irrigation water (mm), $E_{pan}$ the cumulative evaporation between each irrigation interval (mm) and $K_{cp}$ is the plant-pan coefficient. Evaporation between the irrigation intervals was measured with US Weather Bureau Class A pan located in the center of greenhouse. Irrigation water was applied in the 2-day frequency and drip irrigation method was used. Required irrigation water was measured by flow meter device at the head of each plot.

Irrigation water (3 l s$^{-1}$) was supplied from a deep well drilled in the area. Quality properties of irrigation water are given in Table 2. The water is placed in $C_2S_1$ class with low sodium risk, medium EC value. Since there is no recorded problem with water quality, it is well suited for irrigation.

Crop evapotranspiration ($ET_c$) was estimated using the following form of the water balance equation:

$$ET_c = (SWC_{t0} - SWC_{t1}) + IW - D \qquad (2)$$

where $(SWC_{t0} - SWC_{t1})$ is the change in volumetric soil water content between two measurement dates ; $IW$ and $D$ are respectively the total volumes of applied irrigation water and collected drainage for the period under consideration. The water content of plant root depth (0.60 m) was determined by gravimetric method before irrigation water application [18] and monitored in 30 cm depth increments to 0.9 m after irrigation for each irrigation treatments. Monitoring the soil water content in the plots revealed that deep percolation below 0.6 m depth was negligible.

In this study, the Stewart model has contributed to define the relationships between yield and ET (Eq.2) [19, 20].

$$\left(1 - Y_a . Y_m^{-1}\right) = k_y \left(1 - ET_a . ET_m^{-1}\right) \qquad (3)$$

where $Y_a$ is the actual yield (t ha$^{-1}$), $Y_m$ is the maximum yield (tha$^{-1}$), $ET_a$ is the actual evapotranspiration (mm) and $ET_m$ is the maximum evapotranspiration (mm). Values of $k_y$ indicate the response factor of lettuce to deficit irrigation.

The water use efficiency (WUE) was determined to evaluate the productivity of irrigation in the treatments. WUE and irrigation water use efficiency (IWUE) are two terms used to promote the efficient use of irrigation water at the crop production level [21].

**Table 1.** Some of chemical and physical properties of experimental field soil.

| Soil depth (cm) | γ (g.cm$^{-3}$) | Soil type | Field capacity (%) | Wilting point (%) | pH | Total salt (%) | $CaCO_3$ (%) | Organic matter (%) | Available (kg da$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | P | K |
| 0-30 | 1.34 | SL | 19.66 | 11.94 | 7.99 | 0.058 | 5.67 | 2.94 | 1.53 | 38.35 |
| 30-60 | 1.37 | SL | 17.26 | 9.98 | 8.04 | 0.051 | 8.49 | 1.39 | 1.24 | 19.52 |

γ:Unit weight of soil, SL:Sandy loam, P: Phosphor, K: Potassium.

**Table 2.** Chemical composition of irrigation water used in the experiment.

| Water source | $EC_{25}x(10^6)$ | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | pH | Class | SAR |
|---|---|---|---|---|---|---|---|---|
| | | (me L$^{-1}$) | | | | | | |
| Deep well | 715 | 2.3 | 2.56 | 9.25 | 5.7 | 7.12 | $C_2S_1$ | 0.85 |

**Table 3.** Relationship between the decrease in relative water use and decrease in relative yield and yield response factor for lettuce irrigated by a drip system.

| Irrigation treatment | Yield ($t\ ha^{-1}$) | Applied water (mm) | ETa (mm) | ETa/ETm | Ya/Ym | 1-ETa/ETm | 1-(Ya/Ym) | Ky |
|---|---|---|---|---|---|---|---|---|
| $K1_{cp}$ | 15.10a | 485 | 511.0 | 1.000 | 1.000 | 0.000 | 0.000 | 0.00 |
| $K2_{cp}$ | 12.05b | 366 | 407.0 | 0.796 | 0.798 | 0.204 | 0.202 | 0.99 |
| $K3_{cp}$ | 7.90c | 247 | 298.0 | 0.583 | 0.523 | 0.470 | 0.477 | 1.14 |
| $K4_{cp}$ | 3.50d | 129 | 187.0 | 0.366 | 0.232 | 0.634 | 0.768 | 1.21 |
| $K5_{cp}$ | 2.17e | 52 | 78.0 | 0.153 | 0.144 | 0.847 | 0.856 | 1.01 |

WUE was calculated as the ratio of yield (YLD) to $ET_a$, given as WUE = YLD/$ET_a$ ($t\ ha^{-1}\ mm^{-1}$). IWUE was estimated by following equation;

$$IWUE\left(tha^{-1}mm^{-1}\right)=\frac{YLD-YLD_{rainfed}}{IRGA} \qquad (4)$$

where $YLD_{rainfed}$ is the yield obtained from the rainfed treatment or dryland yield and IRGA is the seasonal irrigation amount used in millimeter.

In the harvesting time, 61 days after the seedlings were transplanted; the plants were fully developed and had the size, height, colour and the flavour characteristics of the species. Harvested plants from each plot were evaluated immediately according to yield, plant height, head diameter, leaf number and dry matter.

All data were subjected to analysis of variance (ANOVA) for each character using MSTAT-C (version 2.1-Michigan State University 1991) and MINITAB (University of Texas at Austin) software. The significance of irrigation treatments were compared by the Duncan test at the 0.05 and 0.01 probability levels [22].

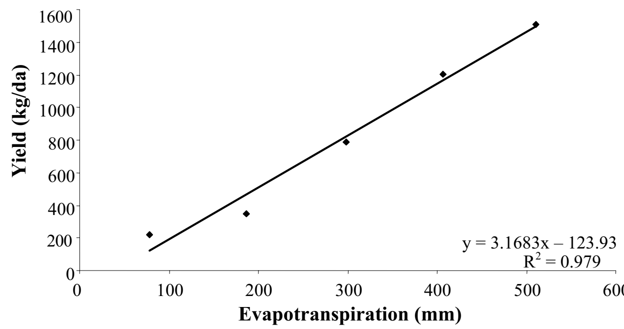


***Figure 1.*** The relationship between crop evapotranspiration and yield.

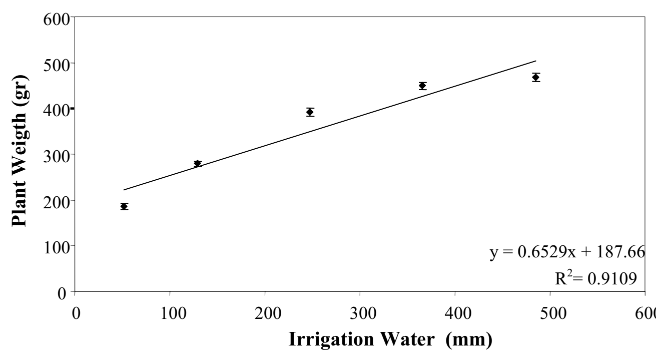


***Figure 2.*** The relationship between irrigation water and plant weight (The errors bars are SE of 15 plants).

## Results and Discussion

***Water applied and water used:*** After planting, 52 mm irrigation water was applied to all treatments to bring the soil water content in 0–60 cm soil depth up to level of field capacity. Irrigation treatments were started measuring of evaporation from Class A pan after the first irrigation application. The maximum amount of water applied to the crop was 485 mm in the $K1_{cp}$ treatment while the minimum amount was 52 mm in the $K5_{cp}$ treatment during the experiment year. The amount of water applied to other treatments ranged between 366–129 mm values. Seasonal evapotranspiration ($ET_c$) was increased with the applied irrigation water and ranged from 511.0 to 78 mm for $K1_{cp}$ and $K5_{cp}$ treatments, respectively (Table 3). These results were in agreement with literature data [23, 24].

Linear relationships were observed between the crop evapotranspiration ($ET_c$) and yield ($Y_a$). The equation for the relationship was $Y_a = 3.1683ET_c – 123.9$ with $R^2 = 0.98$ (Fig. 1). Irrigation significantly increased marketable yield of lettuce [25]. In our study, irrigation treatments significantly affected yield (Fig.2), the highest values were found as 15.10 and 12.05 $t\ ha^{-1}$ in $K1_{cp}$ and $K2_{cp}$ treatments, respectively (Table 4).

Other treatments gave 25.3, 91.1, 331.4 and 595.9% less yield in comparison to $K1_{cp}$ treatment. In a similar study [26], maximum total and marketable yields were 100% of pan evaporation replenishment treatment. Deficit irrigation effect on plant height was significant in the level of $P<0.05$, but only $K5_{cp}$ treatment was in different group. According to results, there was no effect of deficit irrigation on plant height in terms of marketable value. This result was in agreement with earlier results [23, 27]. The highest head diameter was obtained from $K1_{cp}$ treatment, the change in other treatments ($K2_{cp}$ $K3_{cp,}$ $K4_{cp}$ and $K5_{cp}$) was realized as 8, 12, 29 and 62%, respectively. It can be concluded that the deficit of applied irrigation water (25%) is not compatible with the reduction in head diameter (Table4). The effect of deficit irrigation on the number of leaves was significant. While the values of $K1_{cp}$, $K2_{cp}$ and $K3_{cp}$ were in the same group, those of $K4_{cp}$ and $K5_{cp}$ treatments were placed in another group.

**Table 4.** Effects of irrigation treatments on lettuce marketable parameters.

| Irrigation treatment | Plant height (cm) | Head diameter (cm) | Mean leaf number | Dry matter (%) | Yield ($t.ha^{-1}$) |
|---|---|---|---|---|---|
| $K1_{cp}$ | 24.93a | 28.00a | 49.70a | 5.333d | 15.10a |
| $K2_{cp}$ | 24.50a | 25.87ab | 47.87a | 7.697c | 12.05b |
| $K3_{cp}$ | 23.37a | 24.93ab | 43.40a | 9.700c | 7.90c |
| $K4_{cp}$ | 21.20a | 21.67bc | 31.67b | 13.53b | 3.50d |
| $K5_{cp}$ | 16.97b | 17.37c | 27.50b | 18.83a | 2.17e |
| Ttreatments | * | * | ** | ** | ** |
| Blocks | ns | ns | ns | ns | ns |

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level, ns non-significant.

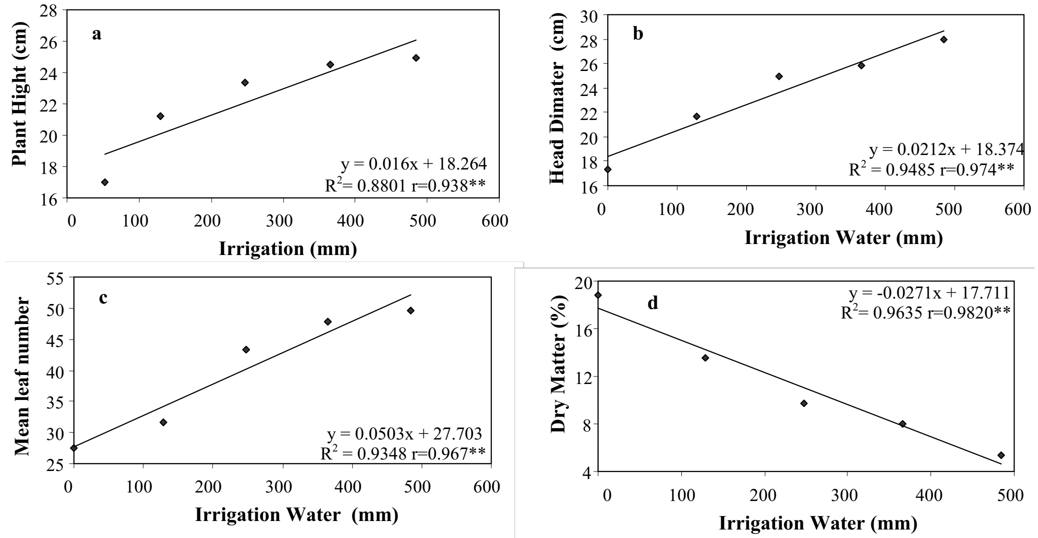


***Figure 3.*** Relationship between applied irrigation water and plant height, head diameter, mean leaf number and dry matter.

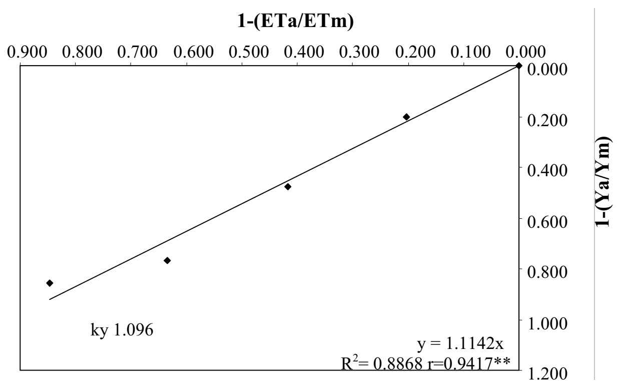


***Figure 4.*** Relationship between relative yield decrease and relative crop evapotranspiration for lettuce throughout the total growing season.

**Table 5.** Total water use efficiency (WUE) and irrigation water use efficiency (IWUE) values for lettuce irrigated by a drip system at different irrigation treatments.

| Irrigation treatment | Yield ($t\ ha^{-1}$) | IWUE $kg\ mm^{-1}$ | WUE $kg\ mm^{-1}$ |
|---|---|---|---|
| $K1_{cp}$ | 15.10 | 2.67 | 2.95 |
| $K2_{cp}$ | 12.05 | 2.70 | 2.96 |
| $K3_{cp}$ | 7.90 | 2.32 | 2.65 |
| $K4_{cp}$ | 3.50 | 1.04 | 1.87 |
| $K5_{cp}$ | 2.17 | 0.00 | 2.78 |

The significant increases in dry matter were found as parallel to irrigation water deficit and the highest and lowest dry matter were found at $K5_{cp}$ and $K1_{cp}$, respectively. This may be attributed to higher plant weight observed from $K1_{cp}$ treatment than those of deficit irrigation treatments. In other words, when the leaves were desiccated relative difference was bigger. These results are similar to literature [24, 26, 28].

Positive linear relation was found among plant height, head diameter and mean leaf number, negative linear relation was found between dry matter and the amount of water applied (IW). The equation for the relationship was *Plant height* = 0,016*IW* + 18,264 with $R^2 = 0.88$ (Fig. 3a), *Head diameter* = 0.0212*IW*+18.374 with $R^2 = 0.95$ (Fig. 3b), *Mean leaf number* = 0.0503*IW+27*.703 with $R^2 = 0.94$ (Fig. 3c) and *dry matter* =– 0.0271*IW* +17.771 with $R^2 = 0.96$ (Fig. 3d).

***Crop yield response factor ($k_y$):*** Crop yield response factor ($k_y$) indicates a linear relationship between the decrease in relative water consumption and the decrease in relative yield. It shows the response of yield with respect to the decrease in water consumption. In other words, it explains the decrease in yield caused by the per unit decrease in water consumption [19, 20]. Seasonal crop response factor was determined as 1.096 for irrigation treatments (Fig. 4). Values of $k_y$ increased with increasing water deficit except in $K5_{cp}$ treatment. This result was much close with the value reported [20] for the cabbage as 0.95. Differences with these results can be attributed to different plant and experimental condition.

***Water use efficiencies:*** WUE and IWUE were different depending on the treatments (Table 5). WUE were 2.95, 2.96, 2.65, 1.87 and 2.78 $kg\ mm^{-1}$, IWUE were 2.67, 2.70, 2.32, 1.04 and 0.00 $kg\ mm^{-1}$ for the irrigation treatments, respectively. These results are similar to literature [24]. When considering IWUE values of $K1_{cp}$ and $K2_{cp}$ treatments, IWUE value of $K2_{cp}$ treatments was found higher than that of $K1_{cp}$ treatment and followed by $K3_{cp}$.

## Conclusions

In this study, irrigation treatments significantly affected yield, plant height, head diameter, leaf number and dry matter. The highest yield was obtained from the $K1_{cp}$ treatment as 15.10 $t\ ha^{-1}$ and the minimum yield was obtained from the $K5_{cp}$ treatment as 2.17 $tha^{-1}$. Yield was significantly reduced as the amount of irrigation water decreased. The rates of reduction in relative yield were 25.3, 91.1, 331.4 and 595.8% at the irrigation treatments, respectively. IWUE value in the $K2_{cp}$ treatment was higher than in the $K1_{cp}$ treatment. Under the conditions that water resources are scarce, it can be recommended that $K2_{cp}$ treatment is most suitable as a water application level for lettuce irrigation by drip irrigation under the unheated greenhouse condition.

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