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ORIGINAL PAPER

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YIELD, QUALITY AND PLANT NUTRIENT CONTENTS OF LETTUCE UNDER DIFFERENT DEFICIT IRRIGATION CONDITIONS

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ABSTRACT

This research was carried out in two separate periods (spring and autumn) in 2018 to reveal the lettuce response of yield, some quality, and plant nutrient content under different water stress conditions. In the study, the effects of different irrigation levels applied with traditional deficit irrigation (TI) and partial root-zone drying (PRD) techniques on lettuce growing were investigated. Lettuce (*Lactuca sativ*a var. *crispa* cv. 'Campania') was used as plant material. There were traditional farmers' method of irrigation (TF), 125% traditional irrigation (TI-125), 100% traditional irrigation (TI-100), 75% traditional irrigation (TI-75), 50% traditional irrigation (TI-50), 125% partial root-zone drying technique (PRD-125), 100% partial root-zone drying technique (PRD-100), 75% partial root-zone drying technique (PRD-75), 50% partial root-zone drying (PRD-50) technique treatments. According to the results of the research, it was determined that different water stress applications were effective on the criteria examined in lettuce. The highest total and marketable yield values were obtained from the TF application, the second-highest values from the TI-125 application, and the lowest yield from the PRD-50 in the autumn period. In the spring season, the lowest yield was obtained from TI-50 and PRD-50 applications. Based on the treatments, the yield values were decreased and changes were experienced with the increase of the water stress in other examined criteria.

Key words: chlorophyll, color, partial root-zone drying, yield

INTRODUCTION

Today, access to sufficient food and safe water is a dream for almost 1 billion people, and within a couple of decades, water scarcity may affect nearly two-thirds of the world's population. By 2050, an additional 2–2.5 billion people are needed to be fed and in this new period water is becoming a central issue [Cosgrove and Loucks 2015]. Water scarcity and water quality are major problems in nowadays agricultural food production [Hatamian et al. 2019, Ebrahimi et al. 2021] leading to a substantial drop in productivity and a threat to food security. Therefore, new agricultural approaches are urgent for this problem [Jiménez-Ariasa et al. 2019]. Different techniques and methods including physical, chemical and biological applications have been shown to better manage crop irrigation and water requirements toward water saving and enhanced water use efficiency [Souri et al. 2009, Souri and Hatamian 2019, Hatamian et al. 2020].

Deficit irrigation was proposed to reduce the irrigation water in a controlled manner [Parvizi et al. 2016]. Regulated deficit irrigation applications increased water efficiency in many crops and the

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income of farmers [Fereres and Soriano 2007, Ebrahimi et al. 2021]. With the partial root-zone drying (PRD) technique, it is also possible to use the existing water resources more efficiently by applying less water similar to traditional deficit irrigation in areas where water is scarce and expensive [Kang et al. 1998]. Increasing the quality of vegetables and reducing water consumption in agricultural production is of great importance [Souri and Römheld 2009, Blanch et al. 2017, Souri et al. 2018a]. Leafy vegetables have high water content and are extremely sensitive to deficit irrigation and drought due to shallow root structure [Kizil et al. 2012]. Since the harvested part is a photosynthetic leaf in leafy vegetables such as lettuce, so their marketable yield is very sensetive to water shortage [Şenyiğit and Kaplan 2013, Souri et al. 2017, Souri et al. 2018b], the irrigation program should be planned well [Casanova et al. 2009].

Yıldırım et al. [2015] investigated the effects of different deficit irrigations on lettuce. According to the evaporation in the Class-A pan and the highest yield values were found as 1544 and 2198 kg da^{-1} for two periods at 1.25 Crop-pan coefficient. In addition, the plants were not affected only by control and 75% irrigation levels in the harvesting period, the other irrigation levels (0%, 25%, and 50%) caused the growth and development of the plants to cease. Psarras et al. [2014] determined that the marketable yield and quality of tomatoes in field conditions were not affected by irrigation regimes, water use decreased by 23% in deficit irrigation and PRD technique and water use efficiency at harvest increased by 20%.

In this study, the effects of traditional deficit irrigation and PRD techniques on yield, some quality, and plant nutrient contents of lettuce were investigated in successive spring and autumn periods under different irrigation regime conditions.

MATERIAL AND METHODS

The study was carried out in a spring-roofed plastic greenhouse (lat. 36°54 N), in two separate cultivation periods (spring and autumn) due to differences in temperature, light intensity and quality in 2018 in Antalya, Turkey. The temperature and humidity values recorded in the greenhouse during the spring and autumn periods are shown in Figures 1 and 2. The physical and chemical properties of the soil sample taken from the research area at a depth of 0–20 cm are given in Table 1.

A drip irrigation system was used as an irrigation method in the research and the irrigation water amount was calculated according to evaporation in the Class-A

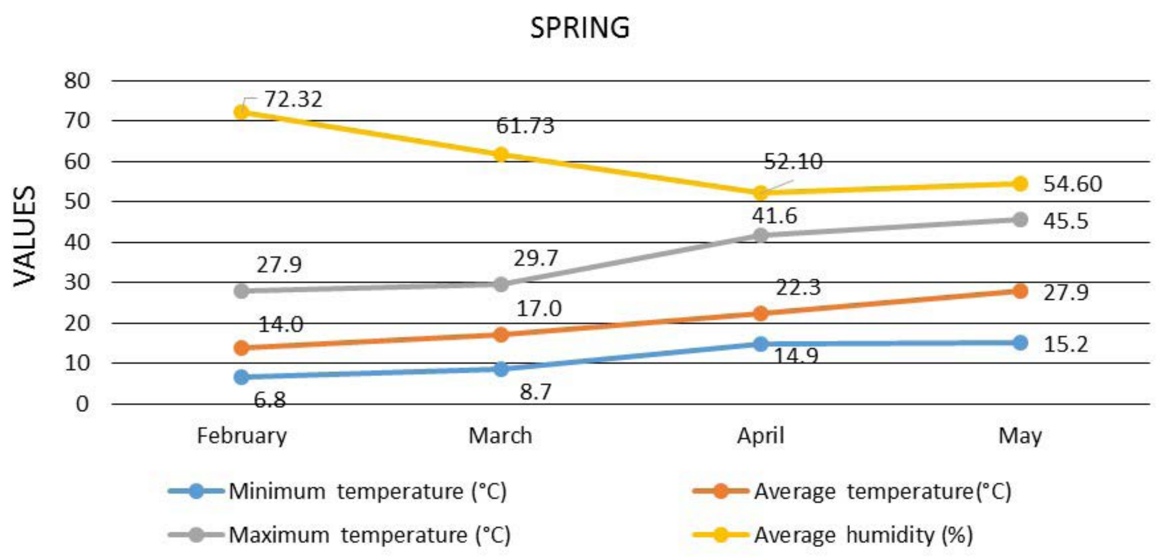


Fig. 1. Temperature and humidity values in the greenhouse in the spring

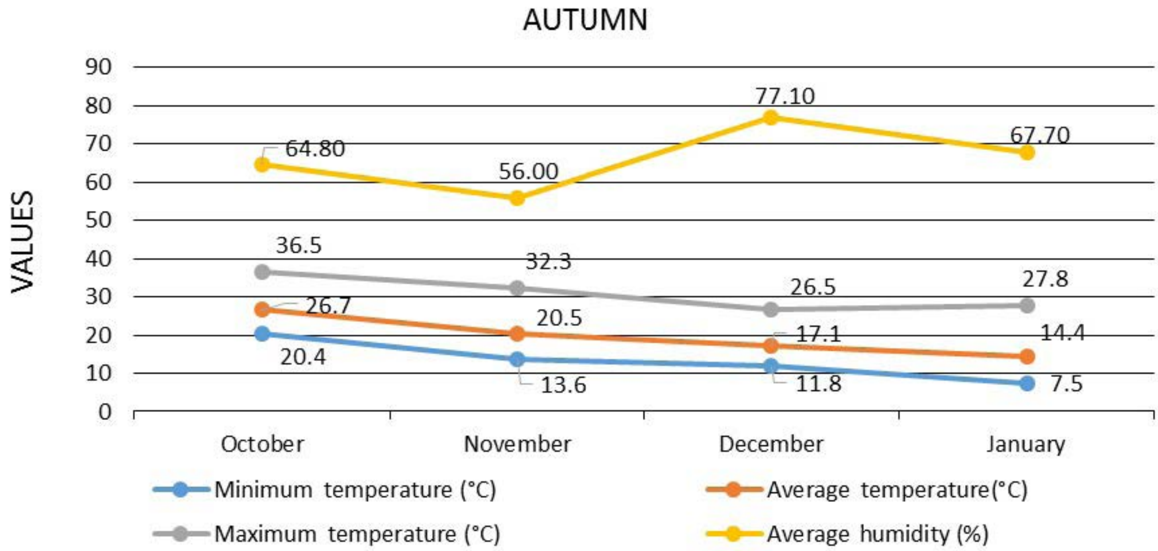


Fig. 2. Temperature and humidity values in the greenhouse in the autumn

Table 1. Some physical and chemical properties of soil

Soil properties	Unit	Value
pH	–	7.58
$CaCO_3$	%	16.62
Electrical conductivity	mS cm^{-1}	0.45
Texture	–	loam
Organic matter	%	1.57
Total N	%	0.077
P	mg kg^{-1}	53.79
K	mg kg^{-1}	230.1
Ca	mg kg^{-1}	3318
Mg	mg kg^{-1}	268.8
Na	mg kg^{-1}	52.9
Fe	mg kg^{-1}	0.906
Mn	mg kg^{-1}	1.192
Zn	mg kg^{-1}	0.440
Cu	mg kg^{-1}	0.292

Table 2. Description of irrigation treatments

Treatments	Descriptions
TF	traditional farmers' method of irrigation where irrigation management was left to the full control of a grower
TI-125	125% traditional irrigation, all roots of the plant were wetted
TI-100	100% traditional irrigation, all roots of the plant were wetted (control treatment)
TI-75	75% traditional irrigation, all roots of the plant were wetted
TI-50	50% traditional irrigation, all roots of the plant were wetted
PRD-125	125% PRD technique, irrigated sides of the plant root zone were alternated every irrigation
PRD-100	100% PRD technique, irrigated sides of the plant root zone were alternated every irrigation
PRD-75	75% PRD technique, irrigated sides of the plant root zone were alternated every irrigation
PRD-50	50% PRD technique, irrigated sides of the plant root zone were alternated every irrigation

pan. In the present experiment, different amounts of irrigation water applied with traditional farmers' method of irrigation, traditional deficit irrigation, and partial root-zone drying (PRD) techniques were discussed (Tab. 2). While traditional farmers' method of irrigation (TF) was done according to the needs of the lettuce plants, traditional deficit irrigation (TI) and PRD treatments was done once or twice a week according to the development stages of the lettuce plants. Traditional deficit irrigation, which was measured using Class-A pan evaporation data, was applied to the roots on all sides of the plant. Partial root-zone drying technique, which was measured using Class-A pan evaporation data, in which wetted and dry sides of the root zone were interchanged with every irrigation.

Lettuce (*Lactuca sativa* var. *crispa* cv. 'Campania') was used as plant material. Lettuce seedlings were planted in the greenhouse on 5 February in the spring period and on 3 October in the autumn period according to the 50 × 40 cm planting distances. In TF application, lettuce seedlings were planted at 40 cm intervals where each dripper is, while the seedlings were planted between the two drippers in TI-125, TI-100, TI-75 and TI-50 applications. In PRD applications two laterals were placed in each row, dripper gaps on the laterals were planned as 80 cm, and lettuce seedlings were planted with 40 cm distance in the dripper gaps in row. The research was carried out with three replications and the parcel size was 1.28 m^2. The irrigation water and fertilizer was applied with the use of a drip irrigation system. While the water requirement of the plants was taken into account in the application performed under farmer conditions (TF), other applications were irrigated once a week.

There were 10 lettuce plants in plots. Since the first and last plants were considered as external effects in each repetition, the criteria were examined on 8 plants. The first irrigation was done after the seedlings were planted in the plots and fertilization was applied as fertigation as 10–20 kg da^{-1} N, 10–12 kg da^{-1}, P_2O_5 and 18–20 kg da^{-1} K_2O according to Vural et al. [2000] after the seedlings were rooted into the soil.

The amount of water applied to the plots was calculated according to the evaporation amounts in the Class-A pan using the following equation according to Kirda et al. [2004] and Topcu et al. [2007].

$$I = K \times Ep$$

In equation:
I – irrigation water amount (mm),
K – coefficient comprising plant coverage wetted area and pan coefficient (the coefficient K was allowed to change within the range of 0.30–0.50),
Ep – total evaporation (mm) amount from A-class evaporation pan corresponding to irrigation interval.

In this study; head height (cm), stem diameter (mm), leaf number (number/plant), chlorophyll content, L, C and H° color values on lettuce leaves, total soluble solid contents (%), pH, total yield (kg m^{-2}), marketable yield (kg m^{-2}), average head weight (g $unit^{-1}$), macro and micro mineral matter contents were investigated. Total soluble solid contents were determined by digital refractometer, relative chlorophyll contents were measured by SPAD 500 chlorophyll meter, color measurements were made with Minolta CR400 model color chromometer according to Madeira et al. [2003] and Jiang et al. [2017].

The plant samples were rinsed with distilled water after washing with tap water and were dried in an air-forced oven at 65°C to constant weight [Kacar and Inal 2008]. Concentrations of P, K, Ca, Mg, Fe, Zn, Mn and Cu in the digestates were determined by using inductively coupled plasma (Perkin Elmer Optima DV7000-ICP OES), N was determined by a modified Kjeldahl procedure [Kacar and Inal 2008]. Soil samples were taken from the experiment area in the beginning of the experiment and soil samples were analyzed for some physical and chemical properties. Total $CaCO_3$, organic matter, pH, electrical conductivity (EC), texture, total N, P, K, Ca, Mg, Na, Fe, Zn, Mn and Cu in soil samples were determined [Kacar 2009].

The statistical analysis of the data obtained from the research conducted with three replications according to the randomized plot trial design was evaluated with the SAS 2009 Package Program.

RESULTS AND DISCUSSION

Irrigation treatments had significant effects on head height (cm), stem diameter (mm), and leaf number of lettuce (per plant) at $p < 0.05$ level in both periods (Tab. 3). The longest lettuce heads in both periods were found in TF application with 23.25 and 16.57 cm, respectively. In deficit irrigation treatments, the highest head height in the spring period was detected in TI-125 and PRD-125 treatments with 21.25 and 21.17 cm, respectively. The least values were measured in PRD-50 and PRD-100 applications with 18.42 and 18.08 cm in the same group, respectively. In autumn, the highest head height was determined as 14.33 cm in PRD-125, which is one of the PRD techniques, while PRD-75, PRD-50, and TI-50 applications gave the lowest values with 11.43, 11.30 and 11.20 cm, respectively, in the same group.

Head height measurements are compatible with the results of Yıldırım et al. [2015] and Şenyiğit and

Table 3. The effects of different water stress applications on head height (cm), stem diameter (mm) and per plant leaf number on lettuce plants

Treatments	Spring			Autumn		
	head height	stem diameter	leaf number	head height	stem diameter	leaf number
TF	23.25a	31.49a	95.00a	16.57a	23.94a	60.47a
TI-125	21.25b	27.71b	94.43a	13.63bc	24.32a	51.90b
TI-100	20.33bc	26.67b	90.77ab	13.40bcd	12.29bc	46.43bc
TI-75	19.00cd	22.69d	86.68bc	12.07de	17.82bcd	45.00bc
TI-50	18.75cd	22.82d	82.42cd	11.20e	14.87d	37.00d
PRD-125	21.17b	25.75bc	93.58a	14.33b	21.49ab	49.57bc
PRD-100	18.08d	24.05bc	82.33cd	12.90cb	19.15bc	42.00cd
PRD-75	19.42cd	23.17d	81.08d	11.43e	16.01cd	35.57d
PRD-50	18.42d	22.21d	79.25d	11.30e	15.97cd	35.70d
$LSD_{\%5}$	11.6936*	2.5088*	47155*	1.3791	4.1546	7.5716

* Values within each treatment marked by the same letter are not significantly different at $p < 0.05$

Kaplan [2013]. Şenyiğit and Kaplan [2013] tried different irrigation levels for cos lettuce under greenhouse conditions based on Class-A pan evaporation (I1: no irrigation, I2: 25%, I3: 50%, I4: 75%, I5: 100% and I6: 125%) and the highest head height was found in I5 with 31.5 cm, while the shortest was determined in I1 with 11.5 cm. Also, head heights were found as 16.6, 23.5, 26.3, and 21.4 cm in I2, I3, I4, and I6 applications, respectively. It has been stated that leafy vegetables are the most vulnerable crops to water shortage, as adequate water and minerals mainly nitrogen and potassium are required for their optimum growth and quality in fresh consumption [Naiji and Souri 2018, Souri et al. 2019, Mohammadipour and Souri 2019].

As regards to stem diameter, the highest values were measured in TF with 31.49 mm in the spring period, and in TF and TI-125 applications with 23.94 and 24.32 mm in the autumn period, respectively. Among the deficit irrigation applications in spring, the highest values occurred with 27.71 and 26.67 mm, respectively, in traditional deficit irrigation applications, TI-125 and TI-100, while the lowest values were recorded in other irrigations except for PRD-125 and PRD-100. In terms of deficit irrigations in autumn, the highest values were measured in TI-125 with 24.32 mm and PRD-125 with 21.49 mm, while the lowest value was found in TI-50 with 14.87 mm. Karipçin and Şatir [2016] reported that the stem diameter in lettuce under water stress conditions was 11.8 and 10.5 mm in 100% and 50% irrigation levels, respectively.

In spring, the highest number of leaves in lettuce plants was counted in TF, TI-125 and PRD-125 treatments, which are in the same group with 95.00, 94.43, and 93.58 number/plant, respectively, while the lowest number of leaves was recorded with 81.08 and 79.25 number/plant in PRD-75 and PRD-50 treatments, respectively. In autumn, the highest number of leaves was obtained from TF with 60.47 number/plant. Among the deficit irrigations treatments, the highest number of leaves was noted in TI-125 with 51.90 number/plant. Sayılıkan Mansuroğlu et al. [2011] applied nitrogen forms and rates in lettuce under different irrigation levels, and they obtained the leaf numbers like 49.3, 57.7, and 60.9 number/plant from 25%, 50%, and 100% irrigation treatments, respectively, according to Class-A pan evaporation. Karipçin and Şatir [2016] found the leaf amount of lettuce as 53.6 and 48 per plant in 100% and 50% irrigation levels, respectively. In the study conducted by Uyan [2011] in spinach under normal deficit irrigation conditions, it was observed that the number of leaves was higher in full irrigation, and the number of leaves decreased with increasing deficit irrigation. Table 4 presents the effects of different water stress applications on pH and soluble solid (%) in lettuce plants.

The effects of irrigation practices on pH and soluble solids in the juice of lettuce in both periods were found significant at $p < 0.05$ level, except for soluble solid in spring. While the highest pH values were measured in PRD-125 (5.65) and TI-50 (5.64) applications in the spring period and the most acidic lettuce juices were recorded in TF (5.50) and TI-125 (5.52) treatments. In this period, no differences were observed among applications for soluble solids, and the values varied between 4.37–4.93%. While TI-50 (6.09) had the highest pH, the most acidic lettuce juice occurred in PRD-125 (6.01) in autumn. The highest efficiency for soluble solids was in TI-50 (5.08%), PRD-75 (5.08%), and TI-75 (5.07%) experiments and the lowest value was obtained from TF (3.53%). Generally, soluble solids increased with the exacerbation of water stress.

Kirda et al. [2004] reported that the ratio of the soluble solid of tomatoes increased with decreasing water, but there was no significant difference in terms of pH. Acar et al. [2008] found that there was difference in soluble solids ratio in 100%, 80%, and 60% irrigation treatments and the highest soluble solid was in 100% irrigation level under greenhouse conditions according to Class-A pan evaporation container. Topçu et al. [2007] found no difference between traditional deficit irrigation and PRD in respect of soluble solid and pH in tomato juice. Blanch et al. [2017] stated the soluble solid content increases with the increase in water stress. Pejić et al. [2016] found that the soluble solid of watermelon was higher in irrigated conditions than in non-irrigated conditions, contrary to our study. Sun et. al. [2014] compared PRD and DI trials in tomato and determined the highest soluble solid in PRD application. Casa and Rouphael [2014] determined that soluble solids increased as the amount of water decreased in both traditional deficit irrigation and PRD applications in tomatoes. In the same study, although there was no significant difference between

Table 4. The effects of different irrigation treatments on pH and soluble solid (%) in lettuce juice

Treatments	Spring		Autumn	
	pH	soluble solid	pH	soluble solid
TF	5.50c	4.60	6.03bc	3.53d
TI-125	5.52c	4.37	6.04bc	4.20cd
TI-100	5.57abc	4.37	6.01bc	4.55abc
TI-75	5.62ab	4.60	6.03bc	5.07a
TI-50	5.64a	4.93	6.09a	5.08a
PRD-125	5.65a	4.43	6.01c	4.23bcd
PRD-100	5.55bc	4.87	6.03bc	5.03ab
PRD-75	5.62ab	4.77	6.05ab	5.08a
PRD-50	5.60ab	4.80	6.05bc	5.03ab
$LSD_{\%5}$	0.0754	ns	0.0415	0.8247

* Values within each treatment marked by the same letter are not significantly different at $p < 0.05$
ns: non significant

the acidity of fruit juices, it was stated that fruit juices were more acidic in deficit irrigation treatments. Nevertheless, some increase in pH of leaf apoplastic sap is common under water shortage [Marschner 2012, Souri and Hatamian 2019].

The effects of different water stress applications on relative chlorophyll content (leaf SPAD value) in lettuce plants are given in Figure 3. The highest value was measured in TI-50 (37.98), PRD-50 (37.53), and PRD-75 (37.49) practices in the spring period. The least chlorophyll content was recorded in TF (30.36). In the autumn period, like spring, the highest content of chlorophyll was found in TI-50 (37.07) and the lowest in TF (27.92). Due to the low growth of the lettuce leaves in deficit irrigations, the concentration of chlorophyll pigments could be increased. Topakli Solak [2016] reported that chlorophyll values varied between 25.5 and 27.1 in lettuce growing under field and tunnel conditions. Blanch et al. [2017] observed that the lettuce chlorophyll content increased as the water stress increased. Similar to this study, Howladar [2018] found that the chlorophyll content of eggplant was higher in full irrigation. It has been stated that sometimes reduction in leaf cell expansion occurs earlier and faster than reduction in leaf chlorophyll content, and this situation generally results in higher leaf chlorophyll content [Ahmadi and Souri 2018, Souri and Tohidloo 2019, Ahmadi and Souri 2020]. The effects of different water stress applications on L, C, H° color values in lettuce plants are shown in Table 5.

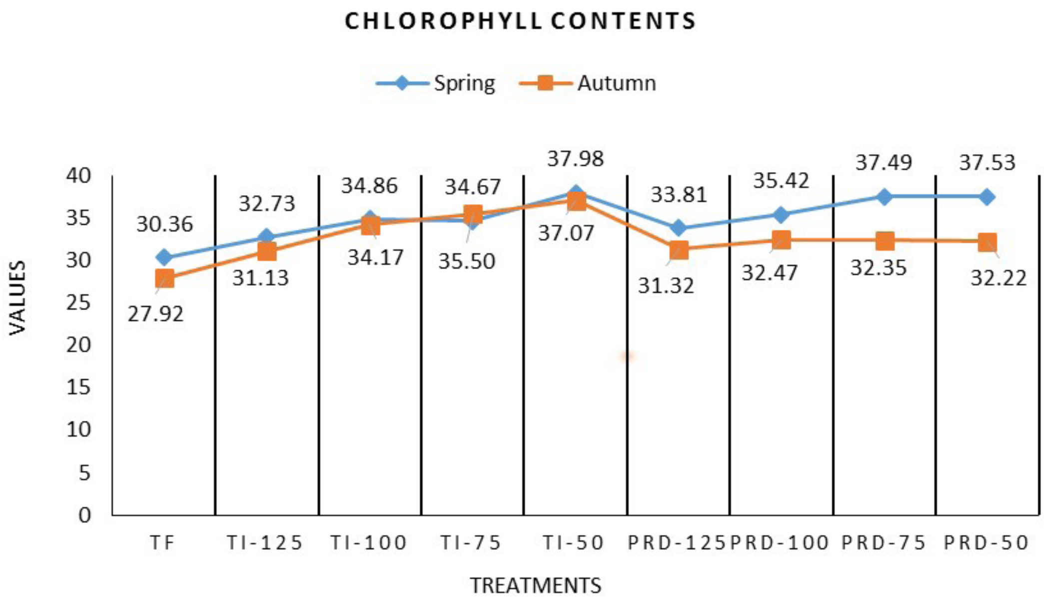
L, C and H° color values measured on lettuce leaves were significantly affected by the treatments in both periods. While the highest L value expressing the brightness was measured in PRD-50 (54.16), the least L was determined in PRD-75 (51.59) in spring. In this period, the highest C value expressing the tone of the leaf color was found in TF (36.15), while there was the least value in TI-50 (32.43). The highest H° angle which shows the vitality of leaf color was in TI-50 (121.20), while the lowest H° was calculated in PRD-50 (119.86). In the autumn period, the highest L and C were obtained from TI-125 (61.14 and 40.77, respectively) and TF (59.79 and 40.51, respectively) treatments in the same group, whereas the lowest L was in PRD-50 (55.35) and the least C is determined in PRD-75 (38.22). Additionally, H° angle was found as the highest in PRD-75 (117.80) and as the lowest in TI-125 (116.46).

Lopez et al. [2013] reported that the C value is low in pale colors and high in vibrant colors. Our results

Table 5. Effects of different irrigation treatments applications on L, C and H° color values of lettuce plants.

Treatments	Spring color values			Autumn color values		
	L	C	H°	L	C	H°
TF	53.99ba	36.15a	119.98bc	59.79a	40.51a	117.33ab
TI-125	52.99abc	33.73bcd	120.97ab	61.14a	40.77a	116.46b
TI-100	52.22abc	33.95abcd	120.49abc	58.47abc	39.24ab	116.74ab
TI-75	52.07abc	34.31abcd	120.56abc	59.03ab	39.35ab	116.60ab
TI-50	51.81bc	32.43d	121.20a	58.89ab	40.00ab	117.49ab
PRD-125	53.67abc	34.74abc	120.14abc	58.22bc	39.42ab	116.79ab
PRD-100	52.34abc	33.38bcd	120.60abc	58.22bc	39.05ab	116.67ab
PRD-75	51.59c	32.69cd	121.03ab	55.80cd	38.22b	117.80a
PRD-50	54.16a	34.99ab	119.86c	55.35d	39.21ab	117.55ab
$LSD_{\%5}$	2.321*	2.2101*	1.0886*	2.7724	2.2718	1.3207

* Values within each treatment marked by the same letter are not significantly different at $p < 0.05$



Note: There were significantly differences among data at $p < 0.05$ level.

Fig. 3. The content of chlorophyll in lettuce leaves

showed that although the green color increased in the lettuce leaves, as supported by Figure 3, with the deficit irrigation in general, they were pale. Şen et al. [2016] determined that the L values were between 41.77 and 41.80, the C values were between 33.56 and 33.80, and the H° values were between 115.78 and 115.84 in the Bovary lettuce variety, while the L values were between 37.27 and 38.70, the C values were between 27.31 and 27.47 and the H° values were between 120.90 and 121.55 in the Romabella cos lettuce variety. It was seen that there were differences with the values obtained from our research, and it was predicted that the differences could arise from applications and types. Blanch et al. [2017] similarly reported that the highest L and C values in lettuce were in the least deficit irrigation applications. The effects of different water stress treatments on the total (kg m^{-2}) and marketable yield (kg m^{-2}) of lettuce plants are shown in Table 6.

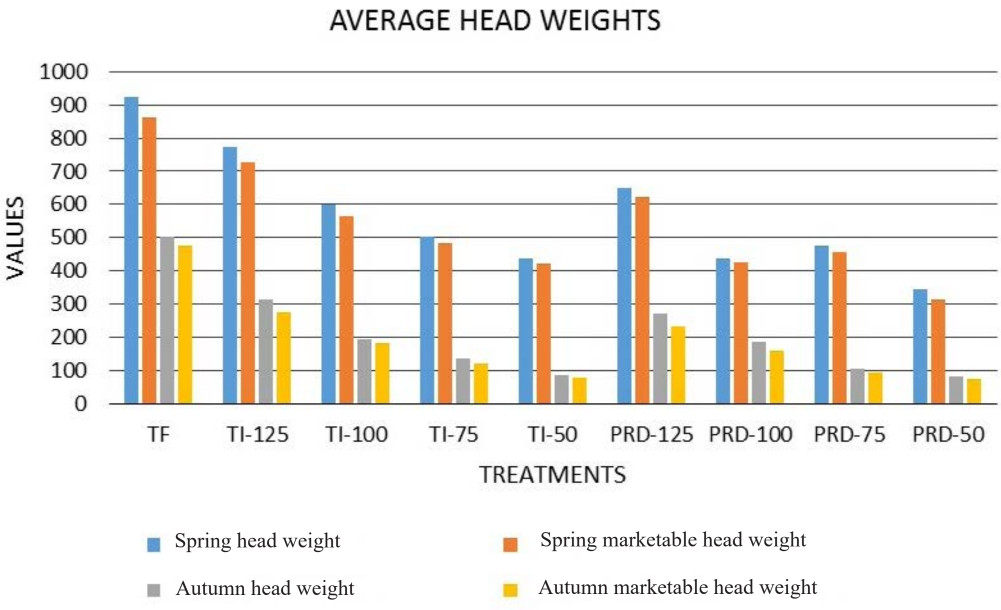
Irrigation practices had significant effects on the total and marketable yield in spring and autumn, and the highest total and marketable yields were obtained from TF in both periods, as 5.77, 5.39, 3.15 and 2.98 kg m^{-2}, respectively. The second highest yield was determined from TI-125, which is the traditional deficit irrigation, with 4.84, 4.53, 1.96, and 1.72 kg m^{-2}, respectively. The lowest total and marketable yields resulted from PRD-50 with 2.16 and 1.98 kg m^{-2}, respectively in spring. Besides, the lowest total and marketable yields were recorded in the TI-50 and PRD-50 applications, which were in the same group with 0.55, 0.51, 0.53, and 0.48 kg m^{-2}, respectively in autumn. In present research, it was seen that the yield reduced as the deficit irrigation increased in both traditional deficit irrigation and PRD applications.

Previous studies on the subject also support these results. Şenyiğit and Kaplan [2013] reached to 460, 1930, 4310, 5980, 8630 and 4550 kg da^{-1} yield values of cos lettuce in 0%, 25%, 50%, 75%, 100% and 125% irrigation levels, respectively, in greenhouse conditions. Yıldırım et al. [2015] stated that the total yield of lettuce under greenhouse conditions was 3742, 3475, 2872, 2520, and 2239 kg da^{-1} in 125%, 100%, 75%, 50%, and 25% irrigation levels, respectively, and the yield increased in parallel with the increase in irrigation water. Howladar [2018] found that the yield of eggplant was higher at full irrigation, as in the autumn period of this study. In a study conducted by Sezen et al. [2019], the highest marketable yield was obtained from full irrigation in the first year of deficit irrigation

Table 6. The effects of different water stress treatments on the total and marketable yield (kg m^{-2}) of lettuce plants

Treatments	Spring		Autumn	
	total yield	marketable yield	total yield	marketable yield
TF	5.77a	5.39a	3.15a	2.98a
TI-125	4.84b	4.53b	1.96b	1.72b
TI-100	3.76cd	3.53cd	1.23d	1.15d
TI-75	3.15de	3.03de	0.85e	0.76e
TI-50	2.75ef	2.64e	0.55f	0.51f
PRD-125	4.05c	3.89bc	1.69c	1.46c
PRD-100	2.75ef	2.67e	1.17d	1.00d
PRD-75	2.99e	2.86e	0.65ef	0.58ef
PRD-50	2.16f	1.98f	0.53f	0.48f
$LSD_{\%5}$	0.6582	0.6586	0.2262	0.2202

* Values within each treatment marked by the same letter are not significantly different at $p < 0.05$



There were significantly differences among data at $p < 0.05$ level

Fig. 4. Effects of different water stress treatments on average head weights (g plant^{-1}) of lettuce plants

studies in red pepper, while it was found in full irrigation and 75% traditional deficit irrigation compared to full irrigation in the second year. Some researchers inform that yield decreases with the increase in water stress. Liu et al. [2020] achieved similar results in 50% traditional deficit irrigation and 50% PRD applications in tomatoes as in the spring of our study. Similarly, Kizil et al. [2012] also reported that yield declined with an increase in water stress (33%). The effects of different water stress applications on average head weights (g plant^{-1}) according to the total and marketable yield values in lettuce plants are given in Figure 4.

The highest total and marketable average head weights in both periods were calculated in TF (923.13, 863.13, 503.33, and 476.23 g plant^{-1}, respectively). TI-125 (774.93, 725.14, 313.30 and 275.83 g plant^{-1}, respectively) followed the TF treatments. The lowest head weights were in PRD-50 (346.67 and 316.25 g plant^{-1}, respectively) in spring, and PRD-75 (104.97, 93.50 g plant^{-1}, respectively), TI-50 (87.43 and 80.93, g plant^{-1}, respectively) in the same group in autumn and PRD-50 (83.57 and 76.13 g plant^{-1}, respectively). Al-Bayati and Sahin [2018] found that the average head weight of lettuce in open field conditions was 934.82 g plant^{-1} with 120% irrigation and the lowest average head weight was 530.89 g plant^{-1} with 60% irrigation subjects. In the same study, the highest average marketable head weight was determined from 120% irrigation with 865.85 g plant^{-1}, and the lowest average head weight was found from 60% irrigation with 475.68 g plant^{-1}. Acar et al. [2008] informed that they obtained total average head weights as 355.17, 340.31, and 338.43 g plant^{-1}, respectively, and their marketable average head weights as 334.78, 321.67, and 308.49 g plant^{-1}, respectively, in 100%, 80% and 60% irrigations of lettuce. In research carried out by Jiménez-Ariasa et al. [2019] for three years, fresh head weights obtained from 95% of the field capacity and 30% fewer deficit irrigations were below the autumn period of our study, they are similar to the spring results. This may be due to ecology, variety, and seasonal differences. In the study conducted by Howladar [2018] in eggplant, the average fruit weight was higher in full irrigation than in the autumn period of this study.

The effects of different water stress applications on macro element contents in lettuce plants in spring and autumn periods are given in Table 7. It was determined that there are significant differences in the macro element contents of lettuce plants compared to the applications except for nitrogen (N) and calcium (Ca) in the spring period. The N content was between 2.64–3.07%, while Ca content was between 1.03–1.40% in autumn. The highest phosphorus (P) content was determined in TF (0.27%), also the lowest content was found in TI-50 (0.11%). The highest potassium (K) was detected in TI-75 (7.28%), whereas the lowest values were seen in TI-100 (5.13%) and TI-125

Table 7. Macro element contents (% DW) in lettuce plants of different irrigation treatments

Treatments	N		P		K		Ca		Mg	
	S	A	S	A	S	A	S	A	S	A
TF	2.67	3.63abc	0.27a	0.33c	6.05ab	5.77ab	1.20	0.86a	0.38bc	0.37a
TI-125	2.75	3.94a	0.24ab	0.39bc	5.10b	4.77b	1.40	0.52b	0.55a	0.27bc
TI-100	2.94	3.70abc	0.19bcd	0.40bc	5.13b	5.09ab	1.27	0.38bc	0.44abc	0.23c
TI-75	2.95	3.93ab	0.14de	0.50abc	7.28a	5.71ab	1.40	0.44bc	0.49abc	0.25c
TI-50	2.64	3.54c	0.11e	0.35c	5.79ab	5.16ab	1.35	0.33c	0.53ab	0.21c
PRD-125	2.66	3.73abc	0.22abc	0.44abc	6.65ab	5.98a	1.33	0.54b	0.45abc	0.32ab
PRD-100	3.07	3.61bc	0.23ab	0.39bc	6.30ab	5.31ab	1.03	0.39bc	0.35c	0.26bc
PRD-75	2.94	3.57c	0.20bcd	0.65a	6.54ab	5.14ab	1.39	0.39bc	0.49abc	0.25c
PRD-50	3.04	3.70abc	0.17cde	0.57ab	5.83ab	5.26ab	1.22	0.43bc	0.46abc	0.26bc
$LSD_{\%5}$	ns	0.3217	0.0629	0.2069	1.8253	1.0506	ns	0.1817	0.1597	0.0729

* Values within each treatment marked by the same letter are not significantly different at $p < 0.05$
ns: non significant; A: autumn; S: spring

Table 8. Microelement contents (mg kg^{-1} DW) in lettuce plants of different irrigation applications

Treatments	Fe		Zn		Mn		Cu	
	S	A	S	A	S	A	S	A
TF	78.27	235.13a	45.93ab	102.27a	65.47	139.87a	4.20ab	5.00a
TI-125	86.87	215.93ab	51.13a	64.40bc	90.47	90.27b	4.13ab	4.60a
TI-100	99.33	174.33abc	38.40ab	59.27bc	77.27	86.53b	3.83ab	3.87ab
TI-75	85.87	200.20abc	46.00ab	49.60c	87.67	71.40b	5.20a	4.40a
TI-50	91.80	185.47abc	28.67b	62.67bc	84.87	73.47b	3.40b	0.73c
PRD-125	102.00	213.20ab	51.20a	73.40abc	75.60	95.67b	4.73ab	1.60bc
PRD-100	74.20	153.53abc	28.00b	86.13ab	64.93	87.33b	3.67ab	1.07c
PRD-75	104.87	143.13bc	40.67ab	76.67abc	90.60	94.40b	4.40ab	0.53c
PRD-50	102.53	130.00c	35.60ab	81.00abc	85.93	101.73ab	4.87ab	0.60c
$LSD_{\%5}$	ns	83.12	19.099	36.235	ns	43.809	1.7934	2.7311

* The difference between values not shown with the same letter are significant at a $p < 0.05$ level
ns: non significant; A: autumn; S: spring

(5.10%) applications in the same group. As regards to magnesium (Mg), while the highest content was found in TI-125 (0.55%) and PRD-100 gave the least content (0.35%). In the autumn period, there were the highest N value in TI-125 (3.94%) and the lowest values in PRD-75 (3.57%) and TI-50 (3.54%) applications in the same group. PRD-75 (0.65%) had the highest P content, while the lowest values were in TI-50 (0.35%) and TF (0.33%) applications. The highest K content of lettuce plant was analyzed in PRD-125 (5.98%) and the lowest in TI-1255 (4.77%). Ca and Mg contents were higher in TF (0.86% and 0.37, respectively) than the others treatments, whereas the lowest Ca value in TI-50 (0.33%) and the lowest Mg values in PRD-75 (0.25%), TI-75. (0.25%), TI-100 (0.23%) and TI-50 (0.21%) irrigations in the same group were analyzed.

Topcu et al. [2007] reported that the highest N contents were found in full irrigation, the second-highest N in PRD applications, and the lowest in traditional deficit irrigations, but there was no statistical difference. Jiménez-Ariasa et al. [2019] described that the differences between the N contents in the leaves were not significant after three years of research, as in the autumn period of this study. However, they noted the K, Ca, and Mg contents to be less in deficit irrigation, unlike our study. Dasgan and Kirda [2007] informed that the K concentration in eggplant leaves is higher in PRD than in traditional irrigation. Liu et al. [2020] conducted that the N accumulation obtained in tomato is similar to 50–75% traditional deficit irrigation and 50–75% PRD applications in the spring period of our study.

According to the research conducted by Sun et al. (2014) on tomatoes, contrary to our study, the highest P (excluding spring), K, Ca, and Mg concentrations were in PRD application compared to PRD and DI. The dry and wet soil in PRD applications facilitates the transport of minerals from the soil volume to the root surface by increasing the N uptake of the roots Wang et al. [2012a]. Also, Wang et al. [2012b] reported that the dry and wet cycle under PRD conditions facilitates P diffusion to the root surface by increasing P uptake as in the spring of our study. Uyan [2011] analyzed the highest N, P, K, Ca and Mg contents in spinach in the control application and found that these decreased as the water stress increased. Kuslu et al. [2008] stated that macro and microelement contents on lettuce decreased with increasing water deficit ratio. The reason for this decrease is related to the decrease in plant water uptake and less root allocations of photoassimilates under water stress. Table 8 shows the effects of different water stress applications on the microelement contents of lettuce in spring and autumn periods.

Variance analysis shows the differences in microelement contents of lettuce plants (except for Fe and Mn) in autumn. It was seen that the Fe content varied between 74.20–104.87 mg kg^{-1} and Mn content varied between 71.40–139.87 mg kg^{-1} in autumn. It was recorded that Fe content varied between 74.20–104.87 mg kg^{-1} and Mn content varied between 71.40–139.87 mg kg^{-1} in autumn. The highest Zn value was analysed in PRD-125 (51.20 mg kg^{-1}) and TI-125 (51.13 mg kg^{-1}) in the same group, while the lowest values were in TI-50 (28.67 mg kg^{-1}) and PRD-100 (28.00 mg kg^{-1}). The highest Cu was obtained from TI-75 (5.20 mg kg^{-1}) and the lowest Cu from TI-50 (3.40 mg kg^{-1}). In autumn, while the highest Fe and Zn minerals were detected in TF (235.13 and 102.27 mg kg^{-1}, respectively), the lowest Fe and Zn contents were determined PRD-50 (130.00 mg kg^{-1}) and TI-75 (49.60 mg kg^{-1}). While the highest Mn value was seen in TF (139.87 mg kg^{-1}), it was followed by PRD-50 (101.73 mg kg^{-1}), all other applications were in the same group. The highest Cu values were taken from TF (5.00 mg kg^{-1}), TI-125 (4.60 mg kg^{-1}) and TI-75 (4.40 mg kg^{-1}) treatments, followed by PRD-125 (1.60 mg kg^{-1}), and others were in the same group. Uyan [2011] reported that the highest value was in the control application concerning microelements in spinach and their contents decreased in the face of increasing deficit irrigation. Transpiration creates the tension required for the roots to absorb the water and nutrient solution. However, this system does not work without water [Mengel et al. 2001]. DI and PRD can cause a decrease in fruit mineral concentration, which is an important quality property, which is an example of deficiencies caused by calcium [Agbemafle et al. 2015].

CONCLUSION

There were significant differences between TF, TI, and PRD irrigation practices in the study. The results of this research showed that traditional irrigation techniques (TF) were higher than deficit irrigation techniques and partial-root drying (PRD) for lettuce growth but under water scarcity conditions, traditional deficit irrigation (TI) applications provided better results than partial-root drying (PRD). During the study, the lowest values were determined in TI-50 and PRD-50 applications, where the least water was applied to the plants. Total soluble solid and relative chlorophyll contents reached the highest values in TI-50 and PRD-50 irrigations. It was observed that the traditional deficit irrigation was slightly better in general when the deficit irrigations were compared in lettuce. As a result, it can be suggested that deficit irrigation may not be the best choice for leaf-consuming vegetables such as lettuce due to the reduction in yield and quality under water scarcity conditions.

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