Pak. J. Agri. Sci., Vol. 60(4), 555-563; 2023
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI:10.21162/PAKJAS/23.135
http://www.pakjas.com.pk[1]

Yield and quality of strawberry under deficit irrigation and fixed partial root drying regimes

Harun Kaman[1,*], Hamide Gübbük[2], Ahmet Tezcan[1], Mehmet Can[1] and Ömer Özbek[3]

[1]Department of Agricultural Structures and Irrigation, Faculty of Agriculture, Akdeniz University, Antalya 07058, Turkey; [2]Department of Horticulture, Faculty of Agriculture, Akdeniz University, Antalya 07058, Turkey; [3]Bati Akdeniz Agr Res Inst, Department of Soil & Water Resources Dept, Antalya, Turkey
*Corresponding author's e-mail: hkaman@akdeniz.edu.tr

Drought is a highly important abiotic stress that affects crops around the world and especially under the Mediterranean climate. This study is focused on strawberry, an important species around the Mediterranean that is suitable for family-owned small-scale businesses. This study aimed to determine the effects of conventional deficit irrigation and fixed partial root drying techniques on the evapotranspiration (ET), yield and quality of Rubygem strawberry species. Strawberry seedlings were planted in the greenhouse in a double row at a planting distance of 30×30 cm. Irrigation was carried out by drip irrigation. The control - full irrigation was based on measurements taken from an A-Class Evaporation Pan. Three conventional deficit irrigation (DI80, DI60 and DI40) and four fixed partial root drying (FPRD100, FPRD80, and FPRD60 FPRD40) were examined. Irrigation water quantities were applied at the 100% (FPRD100/FULL), 80% (DI80 and FPRD80), 60% (DI60 and FPRD60) and 40% (DI40 and FPRD40) levels. The amount of irrigation water ranged between 199.17 and 452.92 mm. It was found that the various water levels affected the ET and the yield (Y). In general, as the amount of water decreased, the ET also decreased. The ET, Y, water use efficiency (WUE) and irrigation water use efficiency (IWUE) were significantly affected by irrigation treatments (LSD 5%). The yield values are ranked from high to low as FULL > FPRD100 > FPRD80 > DI80 > DI60 > FPRD60 > FPRD40 > DI40. As expected, WUE and IWUE values were higher under deficit irrigation levels i.e., DI80, DI60, DI40, FPRD80, FPRD60, and FPRD40. Fruit quality parameters (width, height and average weight) increased with the increase in the amount of applied irrigation water. In addition, fruit firmness values and total phenolic compounds were significantly affected by irrigation level. The results showed that different irrigation levels (100%, 80%, 60% and 40%) affected the yield and yield parameters of strawberry plants. In general, it has been found that, the yield and quality are negatively affected with increases in water deficit (DI40 and FPRD40 treatments). However, the results showed that the fixed partial root drying technique is superior to conventional deficit irrigation applications. As a result of the research, mainly FPRD80 and then DI80, DI60 and FPRD60 are recommended for strawberry cultivation, especially in arid and semiarid regions, depending on the availability of water.
Keywords: Water and yield relations, irrigation water productivity, greenhouse, fresh seedling.

INTRODUCTION

Strawberry *(Fragaria×annanasa* Duch) is a fruit that can be grown under various soil and climate conditions. The fruit has a beautiful appearance, color, aroma, and taste. World strawberry production was approximately 14.5 million tons in 2019 (FAO, 2019). Turkey has been ranked the fourth worldwide after China, the United States (US) and Mexico, with it producing 440.968 t of strawberries in 2018 (FAOSTAT, 2020). Turkey has made significant breakthroughs in strawberry production in recent years and now provides approximately half of the production in the Mediterranean Region (Sarıdaş *et al.*, 2017). Mersin is one of the provinces with the highest share in strawberry production. This province accounts for 40.3% of the total strawberry production in Turkey. Other important provinces producing strawberries are Aydın (28.9%) and Antalya (27.6%) (TUIK, 2017).

Drought stress results in a decrease in yield due to a decrease in photosynthesis and the efficiency of light use. Thus, research on irrigation (which can increase the efficiency of water use without reducing the yield) is extremely important. The partial root-zone drying (PRD) technique has the potential to increase the efficiency of water use. This

Kaman, H., H. Gübbük, A. Tezcan, M. Can and Ö. Özbek. 2023. Yield and quality of strawberry under deficit irrigation and fixed partial root drying regimes. 60: 555-563.
[Received 21 Jun 2023; Accepted 10 Oct 2023; Published 11 Dec 2023]

methodology is based on wetting one-half of the plant roots and leaving the other half relatively dry. Thus, a reduced amount of water is applied effectively (Kang *et al.*, 1998). It has been shown that the efficiency of water use may be higher by periodically wetting half of the root zone. Chaffey (2001) found that application of the PRD technique did not result in a decrease in yield or any other damage. There was even an improvement in fruit taste compared to other conventional deficit irrigation methods. Under the PRD, the closure of stomata and the pause of leaf formation are claimed to result from the production of abscisic acid. Various plant species were grown using PRD (Kaman *et al.,* 2022). Only one study on the cultivation of strawberries in pots was conducted (Dodds *et al.,* 2007).

No study has yet been conducted on strawberry irrigation based on the PRD technique. Water of good quality has become one of the scarcest natural resources because of the frequent droughts that result from global climate change. Therefore, the study of the responses of strawberry to traditional deficit-irrigation and partial root-zone drying (PRD) techniques applied under varying irrigation levels is extremely important. In Pakistan climate resilience has been suggested in response to capacity building and provision of loans to farmers (Ali *et al.,* 2021). Currently, there is a major increase in greenhouse production areas in Turkey and across the world. In this regard, the saving of irrigation water becomes an extremely important issue.

Strawberry plants were grown in a greenhouse under traditional deficit-irrigation and fixed-partial root-zone drying techniques and their effect on yield and quality was investigated.

MATERIALS AND METHODS

The study was carried out from 24 October 2018 to 18 June 2019 in a greenhouse located in the north/south direction in the Research and Application Area of Akdeniz University in Türkiye. The study was planned according to growing season, as it was carried out under completely controlled conditions. The greenhouse is located on 30° 38' 30″ - 30° 39′ 45″ east longitude and 36° 53′ 15″ - 36° 54′ 15″ north latitude.

The Golbası series soils formed on massive travertines fall in the Entisol group of soil because they are fresh soils without much profile development. All the profiles of these soil series, which have an AC horizon and are very fresh, have a clayey-tin texture. They are located in almost flat and near-flat topographies (Sarı *et al.,* 1993).

Analysis of spoiled and unspoiled soil samples taken from different parts of the experimental area were analyzed for physical properties of the soil (Table 1). Based on these values, the greenhouse soil is perfectly suitable as a strawberry growing medium.

Plant material: Fresh seedlings belonging to the Rubygem strawberry species were used as plant material. Rubygem is a new species resulting from the cross *Fragaria* × *ananassa* Duch. It is a high-yielding, medium-hard fruit with a highly aromatic flavor. This species is especially recommended for areas where the winter is not too harsh (Herrington *et al.,* 2007).

Management (planting, fertilization, and spraying) was carried out based on standard agricultural practices.

The drip irrigation system and plot sizes**:** Irrigation and fertilizer applications were carried out with a drip irrigation system with a 2 L h^{-1} dripper flow rate. Soil preparation (levelling, deep plowing) was carried out before planting, and rows were closed with black polyethylene mulch at a thickness of 50 microns. Rows were 25 cm high, with a top surface width of 70 cm and a base surface width of cm. A 40 cm gap was left between the two rows. A drip irrigation system was laterally installed for each row.

Strawberry seedlings were planted on the seedlings in a triangle with an interval of 30×30 cm in double rows. Planting was carried out on October 24, 2018, with 28 plants in each block. The irrigation water amount was calculated according to the evaporation (ET) measured through the Class-A Evaporation Pan placed in the center of the greenhouse. In addition, the electrical conductivity of the irrigation water used in the study was 0.443 dS m^{-1}.

Table 1. Physical properties of soils in the experimental area.

Depth	BD	FC		WP		TAW	
(cm)	(g cm^{-3})	(cm^3 cm^{-3})	(mm)	(cm^3 cm^{-3})	(mm)	(cm^3 cm^{-3})	(mm)
0-10	1.263	0.348	34.83	0.235	23.46	0.114	11.4
10-20	1.270	0.347	34.67	0.235	23.53	0.111	11.1
20-30	1.404	0.385	38.53	0.260	25.98	0.125	12.5
30-40	1.303	0.356	35.59	0.241	24.08	0.115	11.5
	Total (0–40 cm)		143.63		97.06		35.19

BD= Bulk density; FC= Field capacity; WP= Wilting point; TAW= Total available water.

***Experimental treatments*:** Various irrigation technologies for conventional deficit-irrigation and fixed-partial root-zone drying (FPRD) applications were applied together with FULL (Table 2).

Table 2. Irrigation treatments.

Irrigation	Description
FULL	Irrigation water amount was applied uniformly on the two halves of plant root-zone.
DI80	Received 20% less water, compared to FULL irrigation.
DI60	Received 40% less water, compared to FULL irrigation.
DI40	Received 60% less water, compared to FULL irrigation.
FPRD100	Received 1000% water, compared to FULL irrigation; only one half of the plant root zone was relatively irrigated.
FPRD80	Received 20% less water, compared to FULL irrigation; only one half of the plant root zone was relatively irrigated.
FPRD60	Received 40% less water, compared to FULL irrigation; only one half of the plant root zone was relatively irrigated.
FPRD40	Received 60% less water, compared to FULL irrigation; only one half of the plant root zone was relatively irrigated.

***Irrigation water and ET (plant water use)*:** Water was applied to each plant in equal amounts until rooting. Various irrigation regimes were switched on once the plants were three-leaved. Irrigation was applied once a week during the first 10 weeks (in winter) and then twice a week in the spring (depending on seedling development and evaporation). A Class-A Evaporation Pan was placed in the greenhouse, and the amount of irrigation water applied to the FULL was calculated using the equation given below:

$$I = kp \times kc \times Ep \times A$$

I refers to irrigation water (L plant^{-1}); k_p and k_c, refers to respectively - the evaporation pan and crop coefficient (the cover percentage value was initiated from 0.30 and increased up to 1.05 depending on plant growth); E_p refers to the total evaporation measured with the A-Class Evaporation Pan corresponding to the irrigation intervals (mm) and A refers to plant area (m^2).

PR2 Profile Probe access-tubes were installed in plant roots. The access-tubes were used to measure the soil water content distribution profiles using a PR2 Profile Probe. According to the method specified by Köksal et al. (2011) and Kaman and Özbek (2021), the calibration of the PR2 method was made in the soil profile. Afterward, the soil-water content was monitored by the PR2.

***Evapotranspiration (ET), water-use efficiency (WUE), irrigation water-use efficiency (IWUE) and yield response factor (ky)*:** Plant evapotranspiration was determined based on the water-budget using the following equation:s

$$ET = I \pm \Delta S$$

ET refers to plant evapotranspiration (mm); I refer to the amount of irrigation water applied (mm); and ΔS refers to the change in soil-water content between the beginning and the end of the season (mm). There was no capillary water inlet in the study, and precipitation had no effect. Thus, capillary water inlet, surface runoff and precipitation were not included in the plant evapotranspiration equation.

The WUE to irrigation regime was determined using the following equation:

$$WUE = \frac{Y}{ET}$$

WUE refers to water-use efficiency (kg m^{-3}); Y refers to yield (kg da^{-1}); and ET refers to plant evapotranspiration (mm).

The IWUE to irrigation regime was determined using the following equation:

$$IWUE = \frac{Y}{I}$$

IWUE refers to the IWUE (kg m^{-3}); Y refers to the yield (kg da^{-1}) and I refers to the irrigation water applied during the season (mm).

Ky, which is an indicator of the effect of water deficiency on plant yield, was calculated using the following equation proposed by Doorenbos and Kassam (1979) and Stewart et al. (1977):

$$\left[1 - \frac{Ya}{Ym}\right] = ky \times \left[1 - \frac{ETa}{ETm}\right]$$

Ya refers to the actual-yield (t ha^{-1}), which corresponds to actual plant evapotranspiration in the environments where the plant is cultivated; Ym refers to the yield obtained through maximum evapotranspiration in the environments where no water shortage is experienced through the growth season (t ha^{-1}); ky refers to the yield-response factor, which shows the decrease in the yield due to a unit decrease in evapotranspiration; ETa refers to the actual evapotranspiration in environments where the plant is cultivated (mm); ETm refers to the maximum evapotranspiration in environments where the plant is exposed to no water deficit through the growing season of the plant (mm).

***Measurement and observation of fruit quality and other parameters*:** During the research, numerous observations/measurements were made for yield (kg da^{-1}), fruit-weight (g fruit^{-1}), fruit firmness (kg cm^{-2}), vitamin B and C content (Cemeroglu, 2007) and total phenolic components (Rodriguez-Delgado *et al.*, 2001).

Statistical analysis: The experiment was established in three iterative forms according to randomized complete block design. Twenty-eight plants were included in each repetition. Two plants at the beginning and end of the blocks were excluded from the measurement to prevent the plant edge effect. Thus, in each block, 24 plants were evaluated. Statistical analysis was carried out using the SAS program. The LSD test was used for the comparison of the averages.

RESULTS

***Evapotranspiration (ET), water-use efficiency (WUE), irrigation water-use efficiency (IWUE) and yield response factor (ky)*:** Changes in soil-water content were monitored in 100% irrigation water (FULL and FPRD) and 40% irrigation water (DI40 and FPRD40). The soil-water content varied between field capacity and wilting point (Fig. 1, 2).

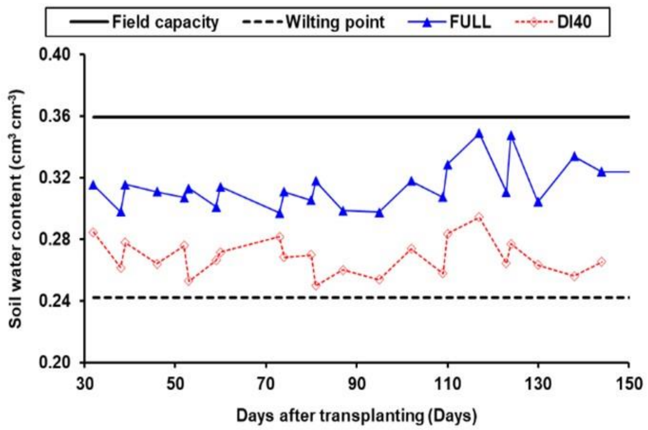

Figure 1. Soil water content during the growth season in FULL and DI40.

Details regarding irrigation (mm), ET, yield (Y, kg da^{-1}), WUE (kg m^{-3}) and IWUE (kg m^{-3}) values are given in Table 3. The amount of irrigation water ranged between 199.17 and 452.92 mm. The highest ET value (428.32 mm) was found in FPRD100, and the lowest ET value (184.09 mm) was found in DI40. As the level of irrigation water decreased, a similar decrease in ET values was also noted. The ET, Y, WUE and IWUE were significantly affected by the irrigation regime (LSD$_{5\%}$). Although the highest efficiency value was recorded in the FULL treatment, it was not significantly different from DI80, DI60, FPRD100, FPRD80 and FPRD60. The efficiency values were ranked from high to low in the following treatments: FULL > FPRD100 > FPRD80 > DI80 > DI60 > FPRD60 > FPRD40 > DI40 (Table 3). The highest WUE value was calculated for DI40, and the lowest was calculated for FULL and FPRD100.

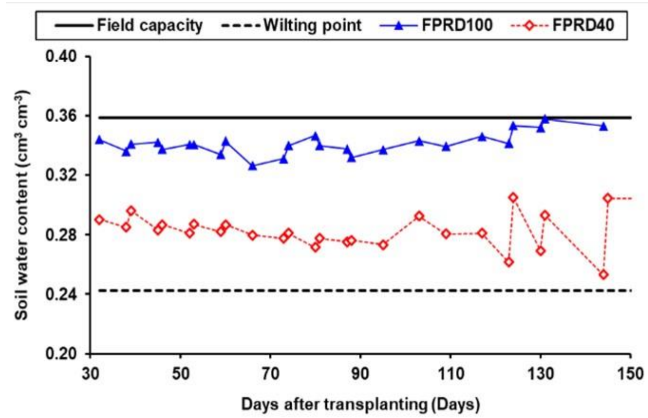

Figure 2. Soil water content during the growth season in FPRD100 and FPRD40.

As expected, WUE values were found to be higher in the deficit irrigation (DI80, DI60, DI40, FPRD80, FPRD60, and FPRD40) treatments (Table 3). Similarly, IWUE values were higher in the DI60, DI40, FPRD60 and FPRD40 treatments (Table 3). The highest IWUE value was found in FPRD40, and the lowest was found in FULL and FPRD100. During the research, the crop was harvested 15 times, and significant differences in yield values were found (LSD 5%) beginning from the first harvest (Table 4). As expected, during the harvest season, the highest yield values were recorded in FPRD100 and FULL, and the lowest were recorded in DI40 and FPRD40. The yield values obtained from the treatments DI80, DI60, FPRD80 and FPRD60 (LSD 5%) did not differ from the yield values of the FULL and FPRD100 (Table 4).
The relationships between irrigation water and yield and between ET and yield in conventional irrigation and fixed

Table 3. Irrigation water, ET, yield, WUE, and IWUE in various treatments.

Treatments	I	ET	Y	WUE	IWUE
FULL	452.92	414.34±0.59b	1426.66±106.97a	3.44±0.26b	3.15±0.24c
DI80	368.34	316.26±1.26d	1267.08±178.76abc	4.01±0.57ab	3.44±0.49c
DI60	283.75	261.72±7.54f	1259.78±175.99abc	4.81±0.67a	4.44±0.62ab
DI40	199.17	184.09±2.12h	934.42±135.52c	5.08±0.74a	4.69±0.68a
FPRD100	452.92	428.32±4.33a	1424.58±444.52a	3.33±1.04b	3.15±0.98c
FPRD80	368.34	330.31±0.75c	1312.06±118.89ab	3.97±0.36ab	3.56±0.32bc
FPRD60	283.75	278.19±2.43e	1121.12±206.71abc	4.03±0.74ab	3.95±0.73abc
FPRD40	199.17	197.19±0.73g	945.88±116.32bc	4.80±0.59a	4.75±0.58a

LSD values are means ± standard deviation, means with different letters within columns differ from each other. I=Irrigation water (mm); ET=Evapotranspiration (mm) ($p<0.001$); Y=Yield (kg da^{-1}) ($p<0.01$); WUE=Water-use efficiency (kg m^{-3}) ($p<0.05$) and IWUE=Irrigation water-use efficiency (kg m^{-3}) ($p<0.05$).

Table 4. Cumulative yield (Y, kg da^{-1}) of harvested fruits under different irrigation regimes during harvest events.

Harvest	FULL	DI80	DI60	DI40	FPRD100	FPRD80	FPRD60	FPRD40
1.Harvest	21.45±2.40NS	24.43±.1060NS	14.84±9.96NS	11.16±9.96NS	18.06±3.25NS	25.00±9.45NS	25.58±18.28NS	11.20±8.62NS
2.Harvest	91.06±1.60a	78.67±26.47abc	58.91±12.95abc	56.19±23.99bc	65.81±18.38abc	85.66±15.33ab	73.58±21.39abc	47.41±14.95c
3.Harvest	183.13±6.85ab	197.74±35.79a	181.64±37.69ab	138.03±24.18bc	193.38±39.80ab	176.82±27.46abc	185.33±40.18ab	118.18±45.02c
4.Harvest	264.48±23.22ab	274.52±58.69ab	265.00±37.09ab	216.42±30.34ab	296.87±62.28a	242.05±32.46ab	249.49±35.04ab	207.81±98.17b
5.Harvest	314.33±21.51ab	345.77±32.75ab	326.11±47.13ab	273.59±24.44b	374.81±73.77a	313.76±50.89ab	316.26±52.91ab	266.99±106.09b
6.Harvest	409.65±23.17ab	430.61±45.92ab	414.00±57.19ab	341.43±20.08b	491.43±108.08a	402.70±64.87ab	398.85±63.24ab	331.30±110.82b
7.Harvest	512.77±29.19ab	536.27±41.97ab	521.55±83.66ab	392.68±28.88b	595.01±155.39a	497.42±79.21ab	460.11±83.18ab	400.10±113.29b
8.Harvest	663.53±36.71ab	657.33±84.68abc	623.07±130.78abc	469.61±36.69c	729.21±211.38a	626.62±109.25abc	600.15±42.49abc	487.72±99.75bc
9.Harvest	750.74±49.51ab	737.98±100.81abc	699.04±145.40abc	519.84±62.51c	824.78±267.22a	712.05±112.54abc	652.24±55.28abc	533.08±85.94bc
10.Harvest	891.04±53.66a	828.62±123.67ab	801.02±157.40ab	586.09±97.73b	943.89±322.70a	844.07±102.48ab	743.32±95.46ab	593.20±69.60b
11.Harvest	996.35±84.41a	908.03±137.84abc	889.34±159.65abc	656.63±113.59c	1056.36±359.59a	951.21±101.78ab	819.42±129.10abc	669.40±94.21bc
12.Harvest	1068.33±104.97a	972.58±142.15ab	969.48±150.15ab	721.66±114.58b	1148.76±384.82a	1024.74±99.94ab	882.56±151.67ab	747.23±97.85b
13.Harvest	1273.64±94.08a	1135.01±154.69ab	1133.11±175.54ab	847.82±125.03b	1306.13±434.88a	1184.76±105.83ab	1024.34±179.71ab	877.34±118.32b
14.Harvest	1400.84±97.18a	1250.23±178.35abc	1242.11±182.34abc	921.63±133.86c	1402.29±449.08a	1296.93±115.87ab	1108.76±207.01abc	940.08±115.03bc
15.Harvest	1426.66±106.97a	1267.08±178.76abc	1259.78±175.99abc	934.42±135.52c	1424.58±444.52a	1312.06±118.89ab	1121.12±209.71abc	945.88±116.32bc

LSD, values are means ± standard deviation, means with different letters within columns differ from each other ($p<0.05$). NS: Not Significant.

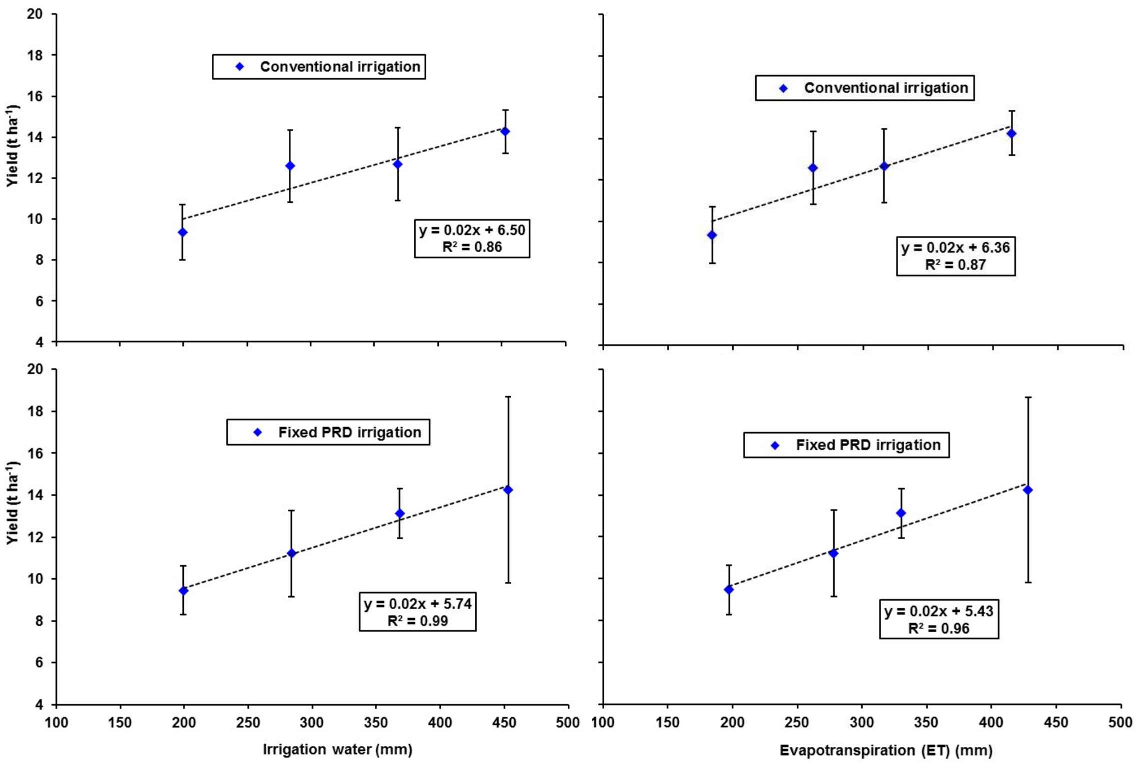

Figure 3. Correlations between irrigation water-yield, and, evapotranspiration-yield of strawberry in conventional irrigation and fixed partial root drying (Fixed PRD) irrigation.

partial root drying (Fixed PRD) irrigation are given in Fig. 3. A strong linear correlation (R^2=0.86) was found between irrigation water depth and yield values in conventional (FULL, DI80, DI60 and DI40) irrigation (Fig. 3). On the other hand, the linear correlation between irrigation water depth and yield values in fixed partial root drying (FPRD100, FPR DI80, FPRD60 and FPRD40) irrigation was found to be stronger (R^2=0.99) (Fig. 3). Along with the decrease in irrigation water, a decrease in yield values was also found (Fig. 3).

A strong linear-correlation (R^2=0.87) was found between ET and yield values in conventional (FULL, DI80, DI60 and DI40) irrigation (Figure 3). However, the linear correlation between ET and yield values in the fixed partial root drying (FPRD100, FPRD80, FPRD60 and FPRD40) irrigation was calculated as stronger (R^2=0.96) (Figure 3). An increase in the yield values was also found due to an increase in ET (Fig. 3). As an indicator of the effect of the proportional decrease in evapotranspiration on the proportional decrease in strawberry yield, Ky were calculated (Fig. 4). The relationship between

Table 5. Fruit yield, fruit width, fruit length and mean fruit weight.

Treatments	Fruit yield (g plant^{-1})	Fruit width (mm)	Fruit length (mm)	Mean fruit weight (g fruit^{-1})
FULL	405.07±30.37 ab	37.95±0.78 a	44.55±0.83 a	26.32±0.71 ab
DI80	359.76±50.76 abc	36.10±1.88 ab	43.09±1.50 ab	23.48±1.77 bc
DI60	348.98±49.97 abc	34.50±1.07 bc	39.81±1.24 bc	20.04±0.47 cde
DI40	265.31±38.48 c	33.85±2.04 bc	39.58±1.11 bc	19.39±1.55 de
FPRD100	433.73±126.21 a	37.93±2.67 a	45.42±3.09 a	27.58±3.44 a
FPRD80	372.53±33.76 ab	35.84±1.82 ab	42.36±1.69 ab	23.54±2.24 bc
FPRD60	318.32±58.69 bc	35.14±0.85 ab	41.95±1.58 ab	22.72±0.59 bcd
FPRD40	268.56±33.03 c	31.80±0.96 c	37.93±2.83 c	16.39±3.14 e

Duncan, values are means ± standard deviation, means with different letters within columns differ from each other. Fruit yield ($p<0.05$); Fruit width ($p<0.05$); Fruit length ($p<0.05$); Mean fruit weight ($p<0.01$).

seasonal evapotranspiration and yield values was found using regression analysis. For the all growing season, Ky values ranged between 0.32 and 0.65 (Fig. 4). In the FPRD60, FPRD40 and DI40 treatments, the Ky values were 0.65, 0.64 and 0.62, respectively. The decrease in the fruit yield of FPRD60, FPRD40 and DI40 treatments was found to be significant.

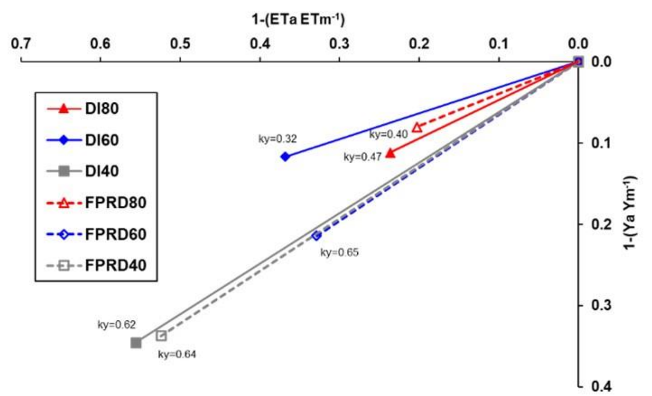

Figure 4. The yield response factors (ky) under various irrigation treatments.

Yield Components: Yield per plant, fruit-width, fruit-height, and average-fruit weight are given in Table 5. All the parameters related to yield were negatively affected by water stress. It was found that fruit width, fruit height and average fruit weight decreased under deficit irrigation compared to the fully irrigated treatments. The differences were found to be significant ($p<0.001$) for each of the parameters mentioned above. However, it was found that irrigation type had no significant effect on these parameters.

The largest fruit-width was obtained in the full treatments (FULL and FPRD100) with 37.950 and 37.933 mm, and the lowest fruit width was obtained in FPRD40, - 31.803 mm. Similarly, the largest fruit lengths were obtained in the full treatments and the 20% deficit, while the lowest fruit length value was obtained in the 60% deficit. The highest value of 27.577 g of fruit^{-1} was found in FPRD100, while the lowest value of 16.387 g of fruit^{-1} was obtained in FPRD40.

Pomological and biochemical analysis**:** Taste is formed by the combination of water-soluble sugars and acids. The fruit firmness value and total phenolic compounds are given in Table 6. These values were significantly affected by various deficit levels.

Table 6. Effect of various irrigation regimes on fruit properties: fruit firmness, and total phenolic compounds.

Treatments	Fruit firmness (kg cm^{-2})	Total phenolic compounds (mg gallic acid kg^{-1})
FULL	0.25±0.03 c	1695.67±169.75 b
DI80	0.23±0.03 c	1690.74±46.96 b
DI60	0.28±0.02 bc	1912.96±88.60 a
DI40	0.33±0.06 ab	1988.27±32.20 a
FPRD100	0.28±0.02 bc	1718.52±175.92 b
FPRD80	0.26±0.03 bc	1730.86±175.38 b
FPRD60	0.28±0.02 bc	1908.02±139.45 a
FPRD40	0.37±0.07 a	1806.79±242.97 ab

Duncan, values are means ± standard deviation, means with different letters within columns differ from each other ($p<0.05$).

DISCUSSION

It was found that the yield of strawberries was affected by various deficit levels. Similarly, the WUE and IWUE were also significantly affected. Similarly, Sarıdaş et al. (2021) stated that the strawberry yield and IWUE significantly differ depending on the amount of irrigation-water. An increase in the amount of irrigation water resulted in increased fruit production, fruit weight, and yield. These results are in accordance with previous findings (Sarıdaş *et al.*, 2017; Rennquist *et al.*, 1982a, 1982b; Yuan *et al.*, 2004; Krüger *et al.*, 1999; Save *et al.*, 1993). As stated by Terry et al. (2009), fruit weight decreased in plants grown under deficit irrigation. There was no significant difference between the yield on conventional irrigation and fixed partial root drying.

However, it was found that the amount of applied irrigation water (100%, 80%, 60%, 40%) significantly affected yield ($p<0.01$). No significant difference was found between the yield values in treatments with full irrigation (FULL and FPRD100) and 20% water deficit (DI80 and FPRD80).

Significant differences were found between the yield in treatments with less water (DI40 - FPRD40) depending on the water amount. Yuan et al. (2004) and Klamkowski et al. (2015) reported values of 545 and 516 g plant^{-1}, respectively, compared with the value of 419.40 g plant^{-1} found in the current study. Liu et al. (2007) and Hoppula and Salo (2007) found that there was a significant decrease in strawberry yield on water stress. Ghaderi et al. (2015) found that water stress reduced fruit yield in two different strawberry species. Adak et al. (2018) found that strawberries irrigated with deficit irrigation had 63.6% lower total yield.

In this study, fruit width, fruit height, average fruit-weight and yield values were negatively affected deficit irrigation. In addition, it decreased under deficit irrigation compared to fully irrigated treatments. Each of these parameters were found to be significantly affected ($p<0.01$). However, it was found that there was no significant effect of irrigation type on all parameters. In addition to increasing the yield of strawberries with increase in the irrigation amount, it has been reported that the average fruit weight also increased significantly (Sarıdaş *et al.,* 2017). In another study, Giné-Bordonaba and Terry (2010) stated that there were significant decreases in the average fruit weight under deficit irrigation conditions. In terms of average fruit weight, it was found that the strawberry species studied here were sensitive to the irrigation amount and had some similar characteristics to the literature already published. Giné-Bordonaba and Terry (2016) found that fruit size decreased by 1.7 fold with deficit irrigation applied during the green period of fruits in some species. Giné-Bordonaba and Terry (2016) found that fruit size decreased by 1.7 fold because of deficit irrigation applied during the greening period. The results of the study are in agreement with previous studies in this aspect (Yuan *et al.,* 2004; Terry *et al.,* 2009).

One of the most important features determining quality of fruit is fruit firmness. Phenols are compounds responsible for the antioxidant capacity of fruits and vegetables. More than 8000 phenolic compounds have been discovered in plants. It has been stated that p-coumaric acid is a phenolic acid found in abundance in strawberries and raspberries (Määtta *et al.,* 2004; Mattila *et al.,* 2006). Chlorogenic acid and quercetin levels are high in the early period of fruit development and decrease rapidly as the plant develops (Ding *et al.,* 2001). The hydroxycinnamic acids commonly found in strawberries are p-coumaric, ferulic and caffeic acids, which are usually bound to sugars (Määttä *et al.,* 2003; Aaby *et al.,* 2007; Simirgiotis *et al.,* 2009; Määttä *et al.,* 2004; Seeram *et al.,* 2006). The increase in phenolic substances and flavonoids in fruits protects the fruit against microbial spoilage (Öz and Kafkas, 2015). In this study, amount of irrigation on phenolic compounds had no significant effect. However, it has been found that the amount of applied water has a negative effect on phenolic compounds. Phenolic compounds found in fruits increase with the increase in water stress. Sevinç (2019) reported that number of phenolic compounds found in the fruit increased with the increase in water stress in plants grown at varying deficit irrigation levels. Şahiner (2019) reported that limited irrigation practices increased the phenolic compounds found in strawberry. The results obtained in the study show similarities with the results in the literature.

It has been found that the firmness of fruit flesh increases with increasing water stress. The firmness values of the fruit flesh of treatments with the most water deficit were the highest. Similarly, Hoppula and Salo (2007) found that a high soil water content increased the yield but reduced the fruit firmness in the cultivation of perennial strawberries. However, Kapur and Şahiner (2019) found that the application of two different-water levels (IR100 and IR50) and three different-colors of mulch in cultivation of ‘Fortuna’ strawberry species did not affect the fruit flesh firmness.

Conclusion**:** The irrigation amount in the study ranged between 199.17 and 452.92. As a result, it was found that various irrigation levels affected the strawberry yield. The highest ET value was calculated for FPRD100, and the lowest ET value was calculated for DI40.

The results showed that different amounts of irrigation water (100%, 80%, 60% and 40%) affected the yield and yield-related parameters obtained from the strawberry plant. In general, the level of negative impact also increased with the increase in water deficit (in the case of DI40 and FPRD40). However, it was concluded that the fixed partial root drying technique is superior to conventional deficit irrigation. We recommend applying the DI80, DI60, FPRD60 and FPRD80 treatments, depending on the availability of water for strawberry cultivation, especially in arid and semiarid regions.

In addition, due to drought experienced as a result of global warming and climate change, it is also recommended to investigate deficit irrigation regimes in different growing environments and different strawberry varieties.

Conflicts of interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' contribution statements: Conceptualization: HK and HG; methodology: HK and HG; formal analysis: HK, HG and AT; investigation and data curation: HK, AT, MC and ÖZ; writing—original draft preparation: HK, HG and AT; writing—review and editing: HK, HG and AT. All authors have read and agreed to the published version of the manuscript.

Acknowledgements: Prof.Dr. Uri Lavi-Gefel (Retired) (Plant Science, Fruit Tree Sciences) (Agricultural Research Organization-Volcani Center, Israel) is acknowledged for editing the text.

Funding: This study was supported by the Akdeniz University Scientific Research Projects Coordination Unit. Project Number: FKA-2018-3941.

REFERENCES

Aaby, K., D. Ekeberg and G. Skrede. 2007. Characterization of phenolic compounds in strawberry (Fragaria x ananassa) fruits by different HPLC detectors and contribution of individual compounds to total antioxidant capacity. Journal of Agricultural and Food Chemistry 55:4395-4406.

Adak, N., H. Gübbük and N. Tetik. 2018. Yield, quality and biochemical properrties of various strawberry cultivars under water stress. Journal of the Science of Food and Agriculture 98:304-31.

Ali, A., Ghafoor, A., Usman, M., Bashir, M.K., Javed, M.I. and Arsalan, M., 2021. Valuation of cost and returns of strawberry in punjab, Pakistan. Pakistan Journal of Agricultural Sciences, 58(1):283-290.

Cemeroglu, B. 2007. Food analysis. Food Technology Society Publication, Ankara, Turkey, pp. 168-171.

Chaffey, N. 2001. Restricting water supply enhances crop growth. Trends Plant Science 6: 346.

Ding, C.K., K. Chachin, U.Y. Yoshinori, Y. Imahori and C.Y. Wang. 2001. Metabolism of phenolic compounds during loquat fruit development. Journal of Agricultural and Food Chemistry 49:2883-2888.

Doorenbos, J. and A.H. Kassam. 1979. Yield response to water. FAO Irrigation and Drainage Paper No, 33, Rome, pp 193.

Dodds, P.A.A., J.M. Taylor, M.A. Else, C.J. Atkinson and W.J. Davies. 2007. Partial rootzone drying increases antioxidant activity in strawberries. Acta Horticulturae 744, ISHS.

FAO. 2019. Food and Agriculture Organization of the United Nations.

FAOSTAT. 2020. Agricultural data. (Accessed 10 March 2020). http://www.fao.org/faostat/en/#search/strawberries〉

Ghaderi, N., S. Normohammadi and T. Javadi. 2015. Morpho-physiological responses of strawberry (Fragaria×ananassa) to exogenous salicylic acid application under drought stress. Journal of Agricultural Science and Technology 17:167-178.

Giné-Bordonaba, J. and L.A. Terry. 2010. Manipulating the taste-related composition of strawberry fruits (Fragaria x ananassa Duch.) from different cultivars using deficit irrigation. Food Chemistry 122:1020-1026.

Giné-Bordonaba, J. and L.A. Terry. 2016. Effect of deficit irrigation and methyl jasmonate application on the composition of strawberry (Fragaria x ananassa) fruit and leaves. Scientia Horticulturae 199: 63-70.

Herrington, M.E., C.K. Chandler, J.A. Moisander and C.E. Reid. 2007. ‘Rubygem’ strawberry. HortScience 42:1482-1483.

Hoppula, K.I. and T.J. Salo. 2007. Tensiometer-based irrigation scheduling in perennial strawberry cultivation. Irrigation Science 25:401–409.

Kaman, H. and Ö. Özbek. 2021. Performance Evaluation of PR2 in Determination of Soil Water Content. Yuzuncu Yil University Journal of Agricultural Sciences 31:543-550.

Kaman, H., Ö. Özbek and E. Polat. 2022. Response of greenhouse grown cucumber to partial root zone drying and conventional deficit irrigation. Kahramanmaraş Sütçü İmam University Journal of Agriculture and Nature 25(2): 337-347.

Kang, S., Z. Liang, W. Hu and J. Zhang. 1998. Water use efficiency of controlled alternate irrigation on root-divided maize plants. Agricultural Water Management 38: 69-76.

Kapur, B. and Y. Şahiner. 2019. Effects of irrigation levels and mulch applications on pomological properties of strawberry. Turkish Journal of Agriculture - Food Science and Technology 7:355-364.

Klamkowski, K., W. Treder and K. Wojcik. 2015. Effects of lon-term water stress on leaf gas exhange, growth and yield of three strawberry cultivars. Acta Scientiarum Polonorum Hortorum Cultus 14: 55-65.

Krüger, E., G. Schmidt and U. Brückner. 1999. Scheduling strawberry irrigation based upon tensiometer measurement and a climatic water balance model. Scientia Horticulturae 81:409-424.

Köksal, E.S., B. Cemek, C. Artık, K.E. Temizel and M. Taşan. 2011. A new approach for neutron moisture meter calibration: Artificial neural network. Irrigation Science 29: 369-377.

Liu. F., S. Savic, C.R. Jensen, A. Shahnazari, S.E Jacobsen, R. Stikic and M.N. Andersen. 2007. Water relations and yield of lysimeter-grown strawberries under limited irrigation. Scientia Horticulturae 111:128-132.

Määttä, K.R., A. Kamal-Eldin and A.R. Törrönen. 2003. High- performance liquid chromatography (HPLC) analysis of phenolic compounds in berries with diode array and electrospray ionization mass spectrometric (MS) detection: Ribes species. Journal of Agricultural and Food Chemistry 51:6736-6744.

Määtta, K.R., A. Kamal-Eldin and A.R. Törrönen. 2004. Identification and quantification of phenolic compounds in berries of Fragaria and Rubus species (family Rosaceae). Journal of Agricultural and Food Chemistry 52:6178-6187.

Mattila, P., J. Hellstrom and R. Törrönen. 2006. Phenolic acids in berries, fruits, and beverages. Journal of Agricultural and Food Chemistry 54:7193-7199.

Öz, A.T. and E. Kafkas. 2015. Determination of the effects of storage time on physical parameter and biochemical composition of 'Festival' strawberry cultivar. Yuzuncu Yil University Journal of Agricultural Sciences 25:105-112

Rennquist, R.P., J. Breen and L.W. Martin. 1982a. Vegetative growth response of 'Olympus' strawberry to polyethylene much and drip irrigation regimes. Journal of the American Society for Horticultural Science 107:369–372.

Rennquist, R.P., J. Breen and L.W. Martin. 1982b. Effect of polyethylene much and summer irrigation on subsequent flowering and fruiting of 'Olympus' strawberry. Journal of the American Society for Horticultural Science 107: 373–376.

Rodriguez-Delgado, M.A., S. Malovana, J.P. Perez, T. Borges and F.J. Garcia-Montelongo. 2001. Separation pf phenolic compounds by high-performance liquid chromatography with absorbance and fluorimetric detection. J. Chromatogr. 912:249-257.

Sarı, M., T. Aksoy, T. Köseoğlu, M. Kaplan, Ş. Kılıç and N. Pilanalı. 1993. Akdeniz Üniversitesi yerleşim alanının detaylı toprak etüdü ve ideal arazi kullanım planlaması. (in Turkish), Akdeniz Üniv Yayınları, Antalya, 145pp.

Sarıdaş, M.A., B. Kapur, E. Çeliktopuz and S. Paydaş Kargı. 2017. Irrigation regimes and bio-stimulant application effects on fruit quality features at 'Rubygem' strawberry variety. Turkish Journal of Agriculture - Food Science And Technology 5:1221-1227.

Sarıdaş, M.A., B. Kapur, E. Çeliktopuz, Y. Şahiner and S. Paydaş Kargı. 2021. Land productivity, irrigation water use efficiency and fruit quality under various plastic mulch colors and irrigation regimes of strawberry in the eastern Mediterranean region of Turkey. Agricultural Water Management 245:106568.

Save, R., J. Penuclas, O. Maria and L. Serrano. 1993. Changes in leaf osmotic and elastic properties and canopy structure of strawberry under mild water stress. HortScience 28:925-927.

Seeram, P.N., R. Lee, S.H. Scheuller and D. Heber. 2006. Identification of phenolic compounds in strawberries by liquid chromatography electrospray ionization mass spectroscopy. Food Chemistry 97:1-11.

Sevinç, Ş. 2019. Effects of different growing media and irrigation programs on yield and water consumption of strawberry grown in soilless culture. Ege University, MSc in Agricultural Structures and Irrigation pp. 119

Simirgiotis, M.J., C. Theoduloz, P.D.S. Caligari and G. Schmeda-Hirschmann. 2009. Comparison of phenolic composition and antioxidant properties of two native Chilean and one domestic strawberry genotypes. Food Chemistry 113:377-385.

Stewart, J.I., R.H. Cuenca, W.O. Pruitt, R.M. Hagan and J. Tosso. 1977. Determination and utilization of water production functions for principal California crops. W-67 CA Contributing Project Report, University of California, Davis, USA.

Şahiner, Y. 2019. The effects of mulch applications with different irrigation levels on yield, pomological, morphological, physiological and biochemical characteristics in strawberry plant. Çukurova University, Agricultural Structures and Irrigation Science Department, MSc Thesis pp. 87.

Terry, A.L., A.G. Chope and G.J. Bordonaba. 2009. Effect of water deficit irrigation on strawberry (Fragaria×Ananassa) fruit quality. ISHS Acta Horticulturae 842, VI International Strawberry Symposium.

TUİK. 2017. Türkiye İstatistik Kurumu. https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr. (in Turkish) (Last Access Date: 04.06.2018).

Yuan, B.Z., J. Sun and S. Nishiyama. 2004. Effect of drip irrigation on strawberry growth and yield inside a plastic greenhouse. Biosystems Engineering 87:237-245.