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Research Article

Water-yield relationship of greenhouse-grown strawberry under limited irrigation

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Abstract

In this study, the traditional full/deficit irrigation and partial root drying (F-PRD) techniques with the four different amounts of irrigation (100%, 80%, 60% and 40%) were examined on Rubygem Strawberry species under controlled greenhouse conditions, in terms of yield, yield parameters, WUE, IWUE, yield response factor (ky), etc. and their possible reactions have been investigated. In the study in which fresh seedlings were used, planted on the rows in a triangular form at intervals of 20×20 cm in double rows. Irrigation applications were carried out by drip irrigation method and the amount of irrigation water in the control treatment (I100) was calculated using measurements taken from an A-Class evaporation pan. Eight irrigation treatments including four traditional irrigation (I100, I80, I60, I40) and four fixed-partial root drying (F-PRD100, F-PRD80, F-PRD60, F-PRD40) were examined within the scope of the study. In traditional irrigation (I100, I80, I60, I40) applications, both sides of the plant root zone were irrigated. However, during the entire growing season in the fixed-partial root drying (F-PRD100, F-PRD80, F-PRD60, F-PRD40) technique, one-half of the plant root zone was kept wet, and the other half was left relatively dry. The yield values were ranked as, from high to low, F-PRD100>I100>F-PRD80>I80>F-PRD60>I60>I40>F-PRD40. In irrigation treatments, the yield values obtained from I80 and F-PRD80 treatments were statistically similar (Duncan 5%) to the yield values of I100 and F-PRD100 treatments. However, it could be stated that the F-PRD80 is more advantageous. It was found that different amounts of irrigation water (100%, 80%, 60% and 40%) affects the yield and yield-related parameters obtained from the strawberry plants. In general, as the water deficit increased (in the I40 and F-PRD40 treatments), the level of negative impact also increased. As a result of the research, F-PRD80 was proposed for the cultivation of strawberries, particularly, in arid and semi-arid regions, depending on the availability of water.

Keywords: fresh seedling; greenhouse; irrigation water productivity; partial root drying; yield response factor (ky); water-yield relations

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Introduction

As a result of global warming and drought, it is becoming increasingly difficult to access a sufficient amount of usable good quality water. However, it has been the agricultural sector that consumes the most water when all sectors are considered, and it has been also clear day by day that agriculture cannot be performed without good quality water. In recent years, it has been reported that about 77% of the total consumed water in Turkey is used in agriculture (DSİ, 2022). However, irrigation efficiency in Turkey has been 33.4% (Kaman *et al.,* 2016), 28.7% and 42% (Kaman *et al.,* 2017), 47.5% (Cetin *et al.,* 2020) in the studies conducted at different times, and it is still very low. However, in arid and semi-arid regions, the distribution of precipitation cannot meet the plant's water needs during the entire growth season (Yavuz *et al.,* 2021). In this case, irrigation is a basic application to reach the optimum and high-quality yield value (Yavuz *et al.,* 2021). Under these conditions, it has become a necessity to investigate irrigation techniques that use water with the highest efficiency in crop production. These techniques wet half of the plant root area during the entire growing season with fixed-partial root drying (F-PRD) and the other half is left relatively dry. Thus, in regions where water is scarce and expensive, existing water resources are used more effectively by applying less water than in traditional irrigation regimes (Kang *et al.,* 1998). It has been shown that water use efficiency may be higher when half of the plant root zone is wet under the PRD technique than the traditional deficit irrigation method (Chaffey, 2001). Chaffey (2001) revealed that the yield will not decrease if some roots remain dry. It has been reported that plants are not damaged due to lack of water, and there is even an improvement in fruit taste in the PRD technique when compared to other traditional deficit irrigation regimes. Varying and numerous plant species have been investigated under the PRD technique. These studies examined tomatoes (Kirda *et al.,* 2004), maize (Kirda *et al.,* 2005), cotton (Kaman *et al.,* 2006), and cucumber (Kaman *et al.,* 2022). However, no study on the strawberry plants has been conducted in the field conditions.

Strawberry is a kind of fruit that has been used for varying purposes. Fresh strawberry fruit contains dietary fibre, vitamin C, β-carotene, folic acid, and other essential nutrients for human health and nutrition, and it also has an appetizing aroma and taste (Monda, 2017; Rannu *et al.,* 2018). In recent years, the planting of strawberries has been encouraged in Turkey, especially in the Mediterranean Region (Sarıdaş *et al.,* 2021), and Turkey has been the largest strawberry producer country in Europe with a production of 440,968 tons and ranks fourth in the world after China, the United States (USA) and Mexico (FAOSTAT, 2020). Turkey has made significant progress in strawberry cultivation in recent years and makes up about half of the production in the Mediterranean Region (Sarıdaş *et al.,* 2017a). Irrigation is considered one of the most important cultural practices in strawberry growth, as well as in other species. In conditions, where there is insufficient water available, the most important thing to consider to save on irrigation water is considering the deficit irrigation regimes. For this purpose, Nezhadahmadi *et al.* (2015) found significant differences between different characteristics such as the duration of three different strawberry species, environmental and drought stress in a controlled and natural growing environment by applying water deficit [25% (severe stress), 50% (moderate stress) and 75%]. Sarıdaş *et al.* (2017a). found just recently that deficit irrigation causes a decrease in the fruit weight of Rubygem's strawberry species; however, due to the increased consumption quality of consumers, this regime with the increased sugar content and sugar/acid level in fruits have been reported to be an important strategy for strawberry growers. In addition to this study, Sarıdaş *et al.* (2017b) determined that the total fruit size (diameter, length and weight) was the lowest in May due to the increase in temperature and decreased plant viability in strawberry species called Comcat, which is produced from seaweed and special wild plants under four different irrigation regimes. Çeliktopuz *et al.* (2017) found that in Kabarla strawberry species, water stress (deficit irrigation) negatively affects the ecophysiological characteristics of the strawberry plant. Kapur *et al.* (2018) reported that irrigation regimes and growing period affects leaf area, corolla diameter, plant width, number of corolla and number of the leaves.

Although the Mediterranean region of Turkey has sufficient water resources, excessive and unconscious irrigation, together with improper agricultural practices, negatively affects strawberry production. Even though irrigation is widely used for strawberry cultivation, especially greenhouse cultivation, as well as for other crops, the water need of the crop under the F-PRD technique has not yet been defined. As a result, research in strawberry cultivation has been planned in more traditional/classical deficit irrigation regimes and more under pot cultivation. However, no studies have yet been conducted with the use of the F-PRD technique.

In the study, strawberries grown in greenhouses under the controlled conditions under four irrigation levels (100%, 80%, 60% and 40%) with the use of traditional deficit irrigation and fixed-partial root drying (F-PRD) techniques were examined in terms of yield, yield parameters, WUE, IWUE, yield response factor (ky) etc.

Materials and Methods

Climate and soil characteristics of the site

The research was carried out between 24 October 2018 – 18 June 2019 in a glass-covered greenhouse located in the north-south direction in the Research and Application Area of the Faculty of Agriculture of Akdeniz University in Turkey. The study was planned according to a growing season, as it was carried out under completely controlled conditions. The research greenhouse is located between 30° 38′ 30″ - 30° 39′ 45″ east longitude and 36° 53′ 15″ - 36° 54′ 15″ north latitude. Its elevation from the sea is 54 m (Anonymous, 1998). The Gölbaşı series soil formed on massive travertines is considered 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 in texture. They are located in almost flat and near-flat topographies (Sarı *et al.,* 1993). Because of the analysis of spoiled and unspoiled soil samples taken from different parts of the experimental area, some physical properties of the soil were determined, and the results are given in Table 1. According to the values in Table 1, it is evident that greenhouse soil is in very good condition (inland conditions) as a strawberry growing medium.

Table 1. Physical properties of soils in the experimental area

Depth	Bulk density	Field capacity (FC)		Wilting point (WP)		Total available water (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

Plant material

In the study, fresh seedlings belonging to the Rubygem strawberry species were used as plant material. Rubygem is a new (*Fragaria* × *ananassa* Duch). It is a high-yielding, medium-hard species with fruits and is quite aromatic. This species is especially recommended for areas where the winter is not too harsh (Herrington *et al.,* 2007).

The design of the drip irrigation system and plot sizes

The glass-covered greenhouse, oriented in north-south direction, were 16 m × 60 m in size. Firstly, soil preparation was carried out (leveling, deep ploughing). Afterward, soil rows with a height of 25 cm, a top surface width of 70 cm and a base surface width of 110 cm was prepared. Then, a drip irrigation system was installed for each row. Prepared rows were closed with polyethene mulches with a thickness of 50 micron of black colour. Strawberry seedlings were planted on the beds in a triangular geometry at an interval of 20×20 cm in double rows. The seedling planting was carried out on October 24, 2018, with 28 plants in each parcel.

A completely randomised block experimental design, comprising irrigation treatments with three replicates, was used. Each plot was 3 m long and 2 m wide, and between plots was left 75 cm space. Irrigation treatments were placed randomly in the study area.

Irrigation and fertilizer applications were applied continuously with a drip irrigation system. A drip irrigation system with a 2 l h^{-1} dripper flow rate was used in the study. The amount of irrigation water was calculated according to the evaporation measured through the A-Class Evaporation Pan placed in the center of the greenhouse. The general characteristics of the irrigation water used in the study are given in Table 2, and it was assumed safe for irrigation.

Table 2. Physical and chemical properties of irrigation water in the experimental area

EC (dS m^{-1})	pH	SAR
0.443	7.35	0.55

Experimental treatments

In the study, different irrigation technologies for conventional deficit irrigation (DI) and fixed-partial root drying (FPRD) applications were considered together with FULL (Table 3).

Table 3. Irrigation treatments

Irrigation treatment	Description
I100	Control treatment where the FULL amount of irrigation water, which was measured using Class-A pan evaporation data, was applied uniformly on the two halves of plant-root zone.
I80	All roots were wetted but received 20% less water, compared to FULL irrigation.
I60	All roots were wetted but received 40% less water, compared to FULL irrigation.
I40	All roots were wetted but received 60% less water, compared to FULL irrigation.
F-PRD100	Compared with FULL irrigation, the same amount of irrigation water was applied; wet and partially dry halves of the root-zone were fixed every irrigation.
F-PRD80	Compared with FULL irrigation, 20% less water was applied; wet and partially dry halves of the root-zone were fixed every irrigation.
F-PRD60	Compared with FULL irrigation, 40% less water was applied; wet and partially dry halves of the root-zone were fixed every irrigation.
F-PRD40	Compared with FULL irrigation, 60% less water was applied; wet and partially dry halves of the root-zone were fixed every irrigation.

Cultural practices

Planting strawberry seedlings, fertilization and spraying processes were carried out evenly and controlled in line with plant and soil requirements, and thus the experiment is carried out systematically. By calculating all the irrigations performed, the effects of different irrigation regimes were investigated. The N:P: K, MAP/MOP, Urea, etc. fertilizers that were considered missing for the strawberry production were detected in plants during vegetative stage, and phosphoric acid, nitric acid, etc. were given when necessary.

Irrigation water amount and plant water consumption

Beginning from planting the strawberry seedlings in the greenhouse, water was given to each plant in an equal amount until the rooting of plants. Different irrigation regimes were switched once the plants were three-leafed. Irrigation was applied once a week in general (also once a week in winter) at the beginning and then twice a week in spring depending on the seedling development and evaporation. As suggested by Kirda *et al*. (2004), an A-Class evaporation pan was placed in the greenhouse and the amount of irrigation water applied to the Full treatment was calculated using the equation given below taking the evaporation measurements into account. In the equation:

$$I = kp \times kc \times Ep \times A \quad (1)$$

I refers to irrigation water (l plant^{-1}); kp and kc, respectively refers to the evaporation pan (1 was taken) and crop coefficient (the cover percentage value was initiated from 0.30 and increased up to 1.05 depending on plant growth); Ep refers to the total evaporation measured with the A-class evaporation pan corresponding the irrigation intervals (mm) and A refers to plant area (m^2).

PR2 Profile Probe access tubes were installed, mid-way between the drippers and the plant roots. The access tubes were used to measure soil water content distribution profiles, before and after irrigation, using a PR2 Profile Probe. According to the method specified by Köksal *et al*. (2011), and Kaman and Özbek (2021), firstly, the calibration of the PR2 method was made within 40 cm of soil depth. Then, the water content in the soil was monitored by the PR2 method under different soil water content conditions.

Soil-water-content profiles data were used to adjust irrigation water requirement, through changes of the kc value in Eq. (1), to ensure that the envisaged irrigation treatments could indeed be realised, and there was no deep percolation.

Evapotranspiration (ET), water use efficiency (WUE), irrigation water use efficiency (IWUE) and yield response factor (ky)

Plant evapotranspiration (ET) was calculated based on the water budget using the following equation:

$$ET = I \pm \Delta S \quad (2)$$

In equation: ET refers to plant evapotranspiration (mm); I refers to the amount of irrigation water applied (mm) and ΔS refers to the change in water content between the beginning and the end of the season (mm). There was no capillary water inlet in the study. In addition, the study was conducted in the greenhouse, so the precipitation had no effect. For these reasons, capillary water inlet, surface runoff and precipitation, etc. were not included in the plant evapotranspiration equation.

By calculating the plant evapotranspiration and recording the yield values, the water use efficiency for each irrigation regime was calculated using the following equation:

$$WUE = \frac{Y}{ET} \quad (3)$$

In equation: WUE refers to Water use efficiency (kg m^{-3}); Y refers to Yield (kg da^{-1}) and ET refers to Plant evapotranspiration (mm).

Along with recording the irrigation water and yield values applied during the season, the efficiency of irrigation water use for each irrigation regime was calculated using the following equation:

$$IWUE = \frac{Y}{I} \quad (4)$$

In equation: IWUE refers to the irrigation water usage efficiency (kg m^{-3}); Y refers to the Yield (kg da^{-1}) and I refers to the irrigation water applied during the season (mm).

The yield response factor (ky) is an important parameter in the planning of irrigation applications. 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):

$$\left[1 - \frac{Ya}{Ym}\right] = ky \times \left[1 - \frac{ETa}{ETm}\right] \quad (5)$$

In equation: Ya refers to the actual yield (t ha^{-1}) which corresponds to the 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 the 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

Numerous observations and measurements were made for the number of siblings, yield, fruit weight, colour, soluble solids content, pH in fruit juice, fruit hardness, total fruit acidity, vitamin B and C content, aroma, total phenolic components during the study.

Statistical analysis

The experiment was established in three-iterative form according to random parcel experiential design. 28 plants were accommodated in each repetition. However, two plants from the beginning and end of the parcels were excluded from the measurement to prevent the plant edge effect. Thus, each parcel was evaluated on 24 plants.

In the study, statistical analysis of the obtained data was carried out with the help of the SAS program. The Duncan test was used for the comparison of the averages.

Results and Discussion

Irrigation water, evapotranspiration (ET), water use efficiency (WUE), irrigation water use efficiency (IWUE) and yield response factor (ky)

The strawberry seedlings were planted in 20×20 cm intervals on the two rows in a triangular form, the change in soil water content (cm^3 cm^{-3}) was observed in the regimes in which the level of irrigation was 100% (I100 and F-PRD100) and 40% (I40 and F-PRD40) (Figure 1). As can be seen in Figure 1, under the highest and lowest irrigation water applications, the soil water content changed between field capacity (FC) and wilting point (WP) all season, which indicates the correct implementation of the considered irrigation management. It reveals that there are no problems with irrigation applications.

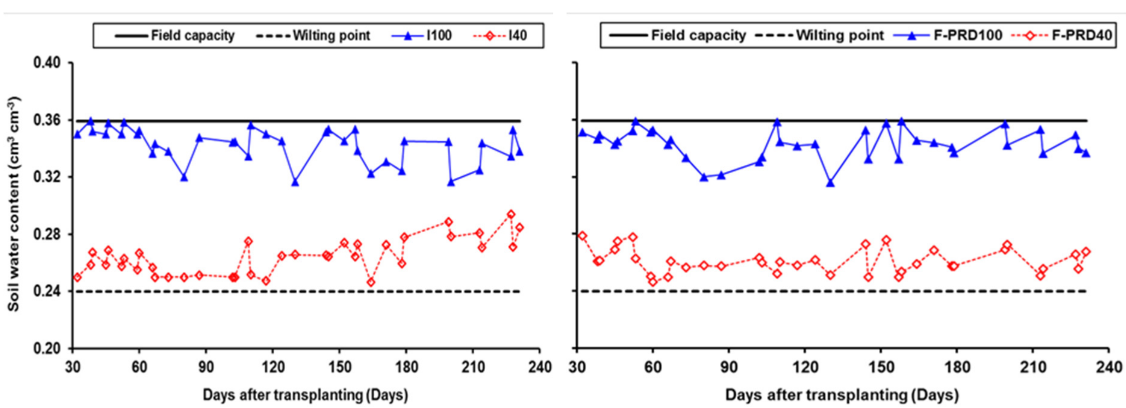

Figure 1. Soil water content (cm^3 cm^{-3}) variation during the growth season

Soil water storage was the highest and changed over the range of FC and WP of water within the 40 cm depth of the root zones under I100 and F-PRD100 irrigation treatments (Figure 1). As expected, the lowest soil water content was determined under I40 and F-PRD40 irrigation treatments. Aforementioned soil water content change, it also resulted in differences in yield values (Figure 1, Table 4, and Table 5).

Table 4. Yield (Y, kg da^{-1}), irrigation (I, mm), evapotranspiration (ET, mm), WUE (kg m^{-3}) and IWUE (kg m^{-3}) values in different experimental treatments grown strawberry under greenhouse condition

Treatments	I (mm)	ET (mm)	Y (kg da^{-1})	WUE (kg m^{-3})	IWUE (kg m^{-3})
I100	490.49	469.33b	1446.72a	3.08	2.95
I80	405.90	383.86d	1135.19ac	2.96	2.80
I60	321.27	318.86e	765.55cd	2.40	2.38
I40	236.71	227.75g	744.62d	3.27	3.15
F-PRD100	490.49	477.78a	1486.37a	3.11	3.03
F-PRD80	405.90	395.65b	1238.34ab	3.13	3.05
F-PRD60	321.27	308.03f	924.22bd	3.00	2.88
F-PRD40	236.71	218.85h	556.96d	2.54	2.35
Duncan 5%		**	**	N.S	N.S.

Differences between the means were showed with different letters ($p<0.05$).
NS: Not Significant, ***: $p<0.001$; **: $p<0.01$; *: $p<0.05$

Table 5. Cumulative yield (Y, kg da^{-1}) of harvested fruit of strawberry under different irrigation regimes during the harvesting season

Harvest no	I100	F-PRD100	I80	F-PRD80	I60	F-PRD60	I40	F-PRD40
1. Harvest	56.6 k	40.9 k	45.2 i	34.9 j	44.1 j	50.9 i	27.7 h	36.8 h
2. Harvest	124.4 ik	99.9 jk	102.6 hi	100.9 ij	99.6 ij	103.8 hi	90.9 h	93.0 gh
3. Harvest	211.6 hj	196.9 ik	182.9 gi	188.0 hi	166.1 hj	191.1 gi	160.0 gh	173.8 fh
4. Harvest	298.8 hj	293.9 hj	263.2 gi	275.0 h	232.5 gj	278.5 fi	229.1 fh	254.6 eg
5. Harvest	356.3 hi	366.6 gi	323.2 fh	320.3 gh	267.9 fi	321.2 ei	260.7 eh	289.2 df
6. Harvest	451.3 gh	475.1 fh	391.1 eg	429.8 fg	339.3 eh	389.1 dh	334.1 dg	345.8 cf
7. Harvest	516.9 fh	548.3 eg	443.5 dg	482.0 ef	369.4 dg	423.1 dg	374.2 cg	373.9 be
8. Harvest	648.3 eg	675.3 df	539.2 cf	600.1de	406.1 dg	520.6 cf	435.5 cf	399.5 ae
9. Harvest	723.7 df	746.0 ce	609.3 ce	660.5 d	436.7 cf	579.2 bf	473.0 be	421.7 ae
10. Harvest	814.8 de	834.8 cd	681.0 bd	741.6 cd	477.5 ce	624.4 ae	506.5 ad	427.1 ae
11. Harvest	935.9 cd	914.6 bc	794.5 bc	846.1 bc	544.6 bd	693.9 ad	561.9 ad	442.6 ad
12. Harvest	1063.5 bc	1064.6 b	900.5 ab	960.0 b	615.2 ac	760.1 ac	610.3 ac	484.3 ac
13. Harvest	1282.7 ab	1321.5 a	1059.8 a	1129.9 a	721.5 ab	861.8 ab	701.2 ab	538.8 ab
14. Harvest	1419.5 a	1465.6 a	1130.0 a	1222.9 a	762.6 a	920.7 a	742.2 a	557.0 a
15. Harvest	1446.7 a	1486.4 a	1135.2 a	1238.3 a	765.5 a	924.2 a	744.6 a	557.0 a
Duncan 5%	**	**	**	**	**	**	**	**

Differences between the means were showed with different letters ($p<0.05$)
NS: Not Significant, ***: $p<0.001$; **: $p<0.01$; *: $p<0.05$

In the study, irrigation water (I, mm), plants' evapotranspiration (ET, mm), yield (Y, kg da^{-1}), water use efficiency (WUE, kg m^{-3}) and irrigation water use efficiency (IWUE, kg m^{-3}) values (Table 4) makes it clear that the amount of irrigation water varies between 236.71 and 490.49 mm. The highest ET value (477.78 mm) was found in F-PRD100 and the lowest ET value (218.85 mm) was found in F-PRD40. In general, as the level of irrigation water decreased, a decrease in ET values was also noted. ET (mm) and Y (kg da^{-1}) values were significantly affected by irrigation treatments (Duncan 5%). Although the highest efficiency value was recorded in the F-PRD100 treatment, it was statistically included in the same group as the I100, I80 and F-PRD80 treatments. The efficiency values are ranked as F-PRD100>I100>F-PRD80>I80>F-PRD60>I60>I40>F-PRD40 (Table 4). The highest WUE value (3.27 kg m^{-3}) was calculated for I40 and the lowest (2.40 kg m^{-3}) was calculated for I60 (Table 4). The highest IWUE value (3.15 kg m^{-3}) was found for I40 and the lowest (2.35 kg m^{-3}) was found for F-PRD40 (Table 4).

During the experiment crops were harvested 15 times, and significant differences in yield values were found (Duncan 5%) in the seventh harvest (Table 5). As expected, the highest yield values were recorded in F-

PRD100 and I100, and the lowest in I40 and F-PRD40 during the harvest season. In general, the yield values obtained from the I80 and F-PRD80 treatments had statistically (Duncan 5%) similar yield values to the I100 and F-PRD100 treatments (Table 5).

A strong linear relationship (R^2=0.91) was found between irrigation water depth and yield values in traditional (I100, I80, I60 and I40) irrigation (Figure 2). On the other hand, the linear relationship between yield values and irrigation water depth in the fixed-partial root drying (F-PRD100, F-PRD80, F-PRD60 and F-PRD40 and F-PRD40) irrigation was calculated to be stronger (R^2=0.99) (Figure 2). With the decrease in irrigation water, a decrease in yield values was also identified (Figure 2). However, the linear relationship between yield values and evapotranspiration (ET, mm) was found to be (R^2=1.00) in the fixed-partial root drying (F-PRD100, F-PRD80, F-PRD60 and F-PRD40) irrigation (Figure 3). An increase in yield values was also found due to an increase in ET (Figure 3).

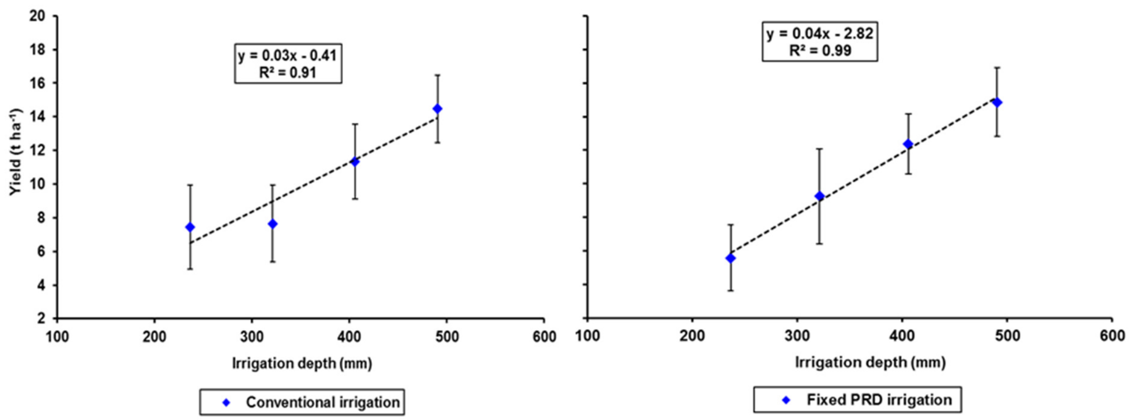

Figure 2. Relationships between total irrigation depth and strawberry yield

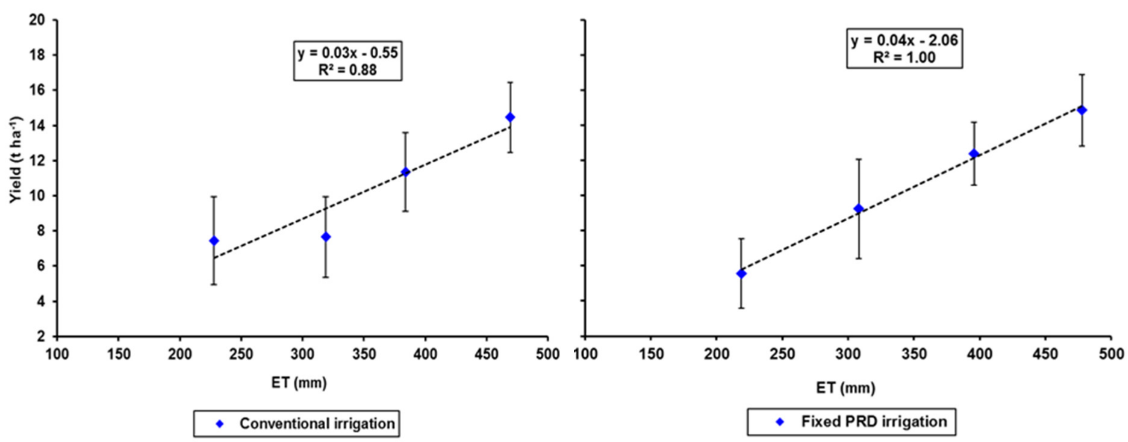

Figure 3. Relationships between evapotranspiration (ET) and strawberry yield

Ky values were calculated as an indicator of the effect of the proportional decrease in plant evapotranspiration on the proportional decrease in strawberry yield (Figure 4). The relationship between seasonal plant evapotranspiration and yield values was determined using regression analysis. For the entire growing season, ky values ranged between 0.92 and 1.47 (Figure 4). Ky values were determined as 1.18, 1.47 and 0.94, in the I80, I60 and I40 treatments respectively. Ky values were calculated as 0.92, 1.05 and 1.15, in the F-PRD80, F-PRD60 and F-PRD40 treatments, respectively.

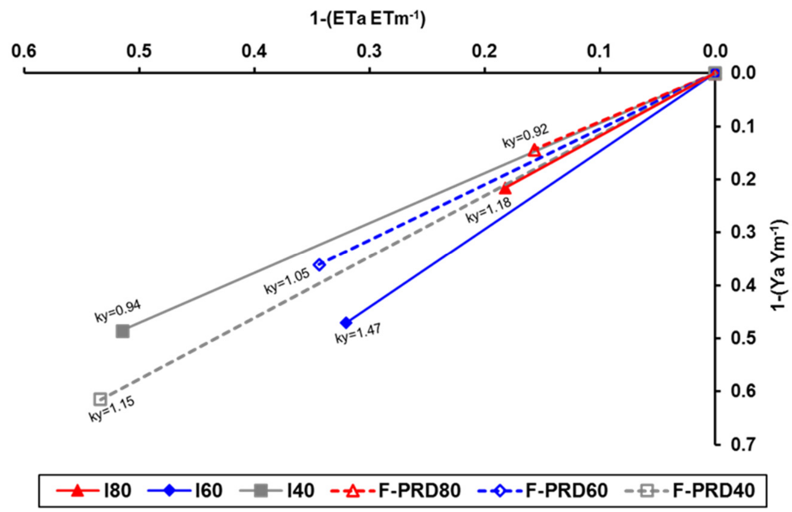

Figure 4. The yield response factors (ky) at various irrigation treatments of the study

This study examined soil water content (cm³ cm⁻³) at the highest (100%: I100 and F-PRD100) and lowest irrigation water levels (40%: I40 and F-PRD40) for the control of irrigation management (Figure 1). The findings obtained revealed similarity with the results of a deficit irrigation study conducted by Sarıdaş et al. (2021), changing between field capacity (FC) and wilting point (WP) along the season. In the study, the vegetation period lasted approximately 238 days. During this period, the amount of irrigation water (I, mm) ranged between 236.71 and 490.49 mm. Considering the time frame, the finding regarding the amount of irrigation water, in general, are similar to those of Kumar and Dey (2012) and Sarıdaş *et al*. (2021). It has shown similarities depending on the amount of irrigation water (Table 4, Figure 2, and Figure 4). Similar findings were reported in the studies conducted by Lozano et al. (2016) and Sarıdaş *et al*. (2021). Any increase in the amount of irrigation water was found to have increased yield. Kapur and Şahiner (2019) reported a decrease in fruit width values with the application of deficit irrigation (50%). With the increase in the irrigation water, it was found that the average fruit weight has also increased significantly as well as the increase in the yield of strawberries (Sarıdaş *et al.,* 2017a). In another study, Giné-Bordonaba and Terry (2010) found that there were significant decreases in the average fruit weight under deficit irrigation regimes.

It was found in this study that the strawberry species examined was sensitive to the amount of irrigation water in terms of average fruit weight. Giné-Bordonaba and Terry (2016) found in their study that the sizes of some fruit species were reduced 1.7 times with the deficit irrigation applied in the green period of plants. These results obtained in our study are similar to previous studies in this aspect (Yuan *et al.,* 2004; Terry *et al.,* 2009). In the same way, when the yield values were examined, it was found that the irrigation regime applied was found not to have had a significant effect on the yield values. There was no significant difference between the yield values of strawberry plants under the traditional/deficit irrigation and fixed-partial root drying technique. However, it was found that the applied water amount significantly affected the yield values ($P<0.001$). Yield values of the fully irrigated treatments were found to have significant differences from the yield values of the treatments with deficit irrigation depending on the amount of water used. When previous studies on yield values of strawberries were examined, it was found that yield decreased with the increase in the water stress (Yuan *et al.,* 2004; Klamkowski *et al.,* 2015). The yield values obtained in our study are also in line with the literature in this aspect.

Yield components

Fruit yield per plant, fruit width, fruit height and average fruit weight values as yield parameters are given in Table 6. All parameters related to yield were negatively affected by water stress. Fruit width, fruit height and average fruit weight were found to have decreased compared to the fully irrigated (100%) treatments. The changes between the treatments were found to be statistically significant (P<0.01) for each of the mentioned parameters (Table 6). The differences between the subjects were found to be statistically significant (P<0.01). However, it was found that there was no significant effect of traditional/deficit irrigation and fixed-partial root drying on all parameters (Table 6). It was found that the largest fruit width was obtained in 33.21 and 32.08 mm with 100% and 80%, and the lowest fruit width was obtained in 29.18 and 28.17 mm with 60% and 40% treatments. Similarly, the largest fruit lengths were obtained in treatments fully irrigated (100%) and 20% deficit irrigation was applied, while the lowest fruit length values were obtained in treatments in which 40% and 60% deficit irrigation were applied. When the average fruit weights were examined, the highest values were obtained in treatments full irrigated (100%) with 20.59 and water deficit was applied with 17.20 mm (20%), respectively. The lowest value was found in the treatments with the most water deficit at 13.85 and 11.98 mm.

Table 6. Some irrigation performance indicators: fruit yield (g plant^{-1}), fruit width (mm), fruit length (mm) and mean fruit weight (g fruit^{-1})

Treatments	Fruit yield (g plant^{-1})	Fruit width (mm)	Fruit length (mm)	Mean fruit weight (g fruit^{-1})
I	193.64	30.782	38.722	15.482
F-PRD	199.03	30.537	37.222	16.325
IM: Irrigation method (I and F-PRD)	NS	NS	NS	NS
100	277.60 a	33.213 a	41.440 a	20.588 a
80	224.64 b	32.075 ab	39.905 ab	17.202 ab
60	159.92 c	29.175 bc	36.766 bc	13.847 bc
40	123.19 c	28.173 c	33.775 c	11.977 c
IWAL: Irrigation water amount level (I%)	***	**	**	**
I100	273.84 a	32.417 ab	40.637 ab	19.437 ab
I80	214.88 abc	31.983 ab	39.813 ab	16.417 abc
I60	144.91 cd	29.290 abc	38.360 ab	13.390 bc
I40	140.95 cd	29.437 abc	36.077 abc	12.683 bc
F-PRD100	281.35 a	34.010 a	42.243 a	21.740 a
F-PRD80	234.40 ab	32.167 ab	39.995 ab	17.986 abc
F-PRD60	174.94 bcd	29.060 bc	35.173 bc	14.303 bc
F-PRD40	105.42 d	26.910 c	31.473 c	11.271 c
IM x IWAL	**	*	*	*

Duncan 5%, differences between the means were showed with different letters (p<0.05).
NS: Not Significant, ***: p<0.001; **: p<0.01; *: p<0.05

The number of siblings and fruit outer colour

At the end of the period, the number of siblings of 5 plants from each treatment were counted in strawberry seedlings (Table 7). When the values of the number of siblings were examined in the study, there was no statistically significant difference between the irrigation regime and irrigation water levels. One of the factors that significantly attract consumers' interest to the product, especially in strawberry fruits, is the external colour of the fruit.

Table 7. Effect of different irrigation regimes on the number of siblings

Treatments	The number of siblings
I	1.98
F-PRD	2.07
IM: Irrigation method (I and F-PRD)	NS
100	2.07
80	2.03
60	2.00
40	2.00
IWAL: Irrigation water amount level (I%)	NS
I100	2.00
I80	2.07
I60	2.07
I40	1.80
F-PRD100	2.13
F-PRD80	1.93
F-PRD60	1.93
F-PRD40	2.27
IM x IWAL	NS

Duncan 5%, differences between the means were showed with different letters ($p<0.05$).
NS: Not Significant, ***: $p<0.001$; **: $p<0.01$; *: $p<0.05$

The effects of different irrigation regimes and different amounts of irrigation water on the outer colour of the fruit in the strawberry fruits examined within the scope of this study are given in Table 8. At the end of the growing season, it was determined that the effect of irrigation regimes and irrigation levels on L, h° and C* values was insignificant in the examination of the fruit exterior colours (Table 8).

Table 8. Effect of different irrigation regimes on outer fruit colour

Treatments	L*	C*	h*
I	36.456	43.553	34.097
F-PRD	36.508	43.188	34.448
IM: Irrigation method (I and F-PRD)	NS	NS	NS
100	36.845	43.892	33.497
80	36.761	45.202	34.608
60	36.471	42.949	34.284
40	35.850	41.438	34.700
IWAL: Irrigation water amount level (I%)	NS	NS	NS
I100	36.917	44.731	44.731
I80	36.413	43.614	43.614
I60	36.343	41.961	41.961
I40	36.152	42.819	42.819
F-PRD100	36.773	43.819	43.819
F-PRD80	37.109	46.404	46.404
F-PRD60	36.600	43.651	43.651
F-PRD40	35.548	39.753	39.753
IM x IWAL	NS	NS	NS

Duncan 5%, differences between the means were showed with different letters ($p<0.05$).
NS: Not Significant, ***: $p<0.001$; **: $p<0.01$; *: $p<0.05$

It has been found that irrigation regimes and the amount of irrigation water do not have a significant effect on colour-related (L*, C*, ho) values, which significantly affect consumers' interest in the product, especially in strawberry fruits. Similarly, the effect of irrigation regime×irrigation level interaction on colour values was found to be insignificant. Çeliktopuz (2019), Kapur and Şahiner (2019), Sevinç (2019), Şahiner (2019) stated that the L*, C* and ho values, which are the external colour values of strawberry fruit, are not affected by different irrigation levels and growth environments. The results obtained in our study are consistent with previous studies. Berk (2013) found that the SSC values obtained from strawberry species ranged between 6.86% and 8.95%. Oguz *et al*. (2017), on the other hand, found the SSC value of strawberries ranged between 9.75% and 14.56%.

Pomological and biochemical analysis

Among the most important parameters that determine the quality of fruits is the taste. Taste is mainly formed by the combination of water-soluble sugars and acids (Table 9). SSC was found not to have been affected by the irrigation regimes and irrigation practices as the change between total fruit acidity and pH values were found to be insignificant. Fruit hardiness/firmness, as one of the most important characteristics of the fruit quality, affects the shelf life of the product, especially the distribution of the product to remote markets and affects fruit endurance. Phenolics, on the other hand, are the compounds responsible for the antioxidant capacity of fruits and vegetables. In this context, the values of fruit hardness and total phenolic compounds are given in Table 9. The values regarding fruit hardness and total phenolic compounds were significantly affected by different irrigation regimes.

Table 9. Effect of different irrigation regimes on some pomological properties and fruit hardness and total phenolic compounds

Treatments	SSC	Total fruit acidity ($g\ L^{-1}$)	pH	Fruit hardness ($kg\ cm^{-2}$)	Total phenolic compounds (mg gallik asit kg^{-1})
I	10.99	8.14	3.96	0.308	1941.00
F-PRD	11.24	8.58	3.91	0.304	2253.10
IM: Irrigation method (I and F-PRD)	NS	NS	NS	NS	NS
100	10.90	8.17	3.96	0.228 b	1789.80 b
80	10.97	7.70	4.02	0.251 b	1797.50 b
60	11.15	8.67	3.91	0.326 ab	2047.80 b
40	11.45	8.92	3.85	0.420 a	2753.10 a
IWAL: Irrigation water amount level (I%)	NS	NS	NS	**	*
I100	10.60	7.33	4.01	0.234 c	2003.10 b
I80	10.67	8.23	3.95	0.235 c	1779.60 b
I60	10.47	8.33	3.95	0.348 abc	1885.60 b
I40	12.23	8.67	3.92	0.416 ab	2125.90 b
F-PRD100	11.20	9.00	3.91	0.222 c	1576.50 b
F-PRD80	11.27	7.17	4.10	0.266 bc	1815.40 b
F-PRD60	11.83	9.00	3.87	0.305 abc	2240.10 b
F-PRD40	10.67	9.17	3.78	0.424 a	3380.20 a
IM x IWAL	NS	NS	NS	*	*

Duncan 5%, differences between the means were showed with different letters ($p<0.05$).
NS: Not Significant, ***: $p<0.001$; **: $p<0.01$; *: $p<0.05$

In this study, the SSC values, the irrigation regime, irrigation level and irrigation regime×irrigation level interactions were found to be statistically insignificant. In addition, the results of the study are similar to those in the literature. It was found that the total fruit acidity values were not affected by the irrigation regimes employed. Similarly, the pH values were found to be insignificant. Fruit hardness, as one of the most important characteristics determining fruit quality, affects the shelf life of products, especially for the distribution of the product to remote markets and affects their endurance. Phenolics, on the other hand, are the compounds responsible for the antioxidant capacity of fruits and vegetables. They are commonly found structures in plants, and more than 8000 phenolic structures have been found so far. It has been reported that p-coumaric acid is a phenolic acid found in abundance in strawberries and raspberries (Määtta *et al.,* 2004; Mattila *et al.,* 2006). It has been reported that 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). Hydroxycinnamic acids, which are commonly found in strawberries are p-coumaric, ferulic and caffeic acids, and their bound forms are usually bound with sugars (Määttä *et al.,* 2003; Aaby *et al.,* 2007; Simirgiotis *et al.,* 2009; Määttä *et al.,* 2004; Seeram *et al.,* 2006).

Fruit hardness in strawberries is an important quality criterion for transportation and post-harvest storage. It was found in this study that the hardness of the fruit flesh was not affected by the irrigation regime. However, it was also found in this study that the effect of the irrigation regime applied on the hardness of the fruit flesh was significant. The hardness of the fruit flesh was also found to have increased with the increasing water stress. It was found that the hardness values of the fruit flesh of the treatments with the highest amount of water deficit were found to be the highest. Hoppula and Salo (2007) conducted a study investigating irrigation programming using a tensiometer in perennial strawberry cultivation and found that high soil water content increased yield but reduced fruit hardness. Kapur and Şahiner (2019) examined the effects of two different irrigation regimes (IR100 and IR50) and three different colours of mulch applications (black, grey and transparent) on fruit quality in the 'Fortuna' strawberry species. It has been found that the fruit flesh hardness is not affected by the irrigation regime employed. Phenolic compounds and flavonoids found in strawberry fruit are compounds with antioxidant properties. Phenol compounds are secondary metabolites found in all plant metabolism and have a role in protecting plants against some pests. The increase of phenolic substances and flavonoids in fruits protects the fruit against microbial spoilage (Öz and Kafkas, 2015).

In the study, there was no significant effect of the irrigation regime on phenolic compounds. However, it has been found that the amount of applied irrigation water has a negative relationship with phenolic compounds and that phenolic compounds found in fruits increase with the increasing water stress. Sevinç (2019) reported that the number of phenolic compounds found in the fruit also increased with the increase of water stress in the strawberry plant grown under different irrigation regimes. Şahiner (2019) reported that deficit irrigation significantly increased the phenolic compounds found in strawberry fruit. In this aspect, the results of the study were found to be similar to the previous studies.

Conclusions

In this study, the effects of traditional deficit irrigation and fixed-partial root drying (F-PRD) techniques on the yield and quality parameters and evapotranspiration of 'Rubygem' strawberry species grown under four irrigation regimes (100%, 80%, 60% and 40%) were investigated. The results of the research have shown that different irrigation regimes (100%, 80%, 60% and 40%) affect the yield and quality parameters of the 'Rubygem' strawberry species. In addition, as the amount of water deficit increased (in the I40 and F-PRD40 treatments), the yield and quality were negatively affected. Out of the irrigation techniques, the fixed-partial root drying technique was found to be generally superior over the traditional deficit irrigation technique. As a result of this research, the F-PRD80 was proposed for strawberry cultivation, especially in arid and semi-arid regions. The soil water content ($cm^3 cm^{-3}$) values were monitored in the study (100%: I100 and F-PRD100 and 40%: I40 and F-PRD40) and ranged between field capacity (FC) and wilting point (WP) thought the season, as expected. The amount of irrigation water was calculated between 236.71 mm and 490.49 mm, and the ET value was calculated between 218.85 mm and 477.78 mm. In general, as the amount of irrigation water decreased, a decrease in ET values was also noted. The yield values are ranked as F-PRD100 > I100 > F-PRD80

> I80 > F-PRD60 > I60 > I40 > F-PRD40. In general, the yield values obtained from the I80 and F-PRD80 treatments were statistically (Duncan 5%) similar to the yield values of the I100 and F-PRD100 treatments. This shows that the F-PRD80 is more advantageous for efficiency. Ky values for the entire growth season ranged between 0.92 and 1.47. It was revealed that any increase in the amount of irrigation water in the study led to greater yields.

All parameters related to yield were negatively affected by water stress. In comparison with fully irrigated (100%) treatments, fruit physical properties (weight, width and height) were found to be lower in plants under deficit irrigation. It has been noted that the colour (L*, C*, ho) values, pH and acidity values of strawberry fruits are not affected by the irrigation regimes and irrigation method. However, it has been found that the effect of irrigation regimes on fruit flesh hardness is important. It has been determined that the hardness of the fruit flesh also increases with increasing water stress. It was found that the hardness values of the fruit flesh of the treatments with the highest amount of water deficit were the highest.

As a result, it was found that different irrigation deficit levels (100%, 80%, 60% and 40%) affect the yield and yield parameters obtained from the strawberry plant. In general, as the amount of deficit increased (I40 and F-PRD40 treatments), the level of negative effect also increased. Thus, it was concluded that the fixed partial root drying technique was generally superior to traditional deficit irrigation. As a result of the research, the F-PRD80 was proposed for strawberry cultivation, especially in arid and semi-arid regions.

Authors' Contributions

Conceptualization: HK, HG, AT, MC and ÖÖ. Data curation: HK, HG, AT, MC and ÖÖ. Formal analysis: HK, HG, AT, MC and ÖÖ. Project administration: HK, HG. Writing - original draft: HK. Writing - review and editing: HK, HG, AT. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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