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Yield Response of Greenhouse Grown Grafted Eggplant to Partial Root Drying and Conventional Deficit Irrigation

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ABSTRACT

Global climate change negatively affects life, thus complicating the production of vegetables. In addition to this, very little is known about eggplant cultivation under different irrigation strategies. For example, although water use efficiency gives better results in some plant species and varieties without any decrease in yield when the partial root drying (PRD) technique is used, the PRD technique has not been adequately examined in eggplant cultivation. The potential reactions of grafted and ungrafted eggplant plants under different irrigation water levels (100%, 80%, 60% and 40%) with the use of the conventional and deficit irrigation and PRD technique were investigated in this study. The research was conducted in a glass greenhouse during two cultivation seasons in 2019 and 2020. Irrigation was applied equally to both grafted and ungrafted eggplant plants using the drip irrigation method. In the study were examined the growth, quality criteria, yield, yield components, WUE, IWUE, and ky of eggplant to determine the reactions of grafted and ungrafted eggplant plants under different irrigation applications. It was found in the study that the method and amount of irrigation water applied had a significant effect on the grafted and ungrafted eggplant plants. Irrigation water was applied in the first and second season respectively between 148.45 and 365.48 mm, 245.61 and 584.84 mm. The statistical differences were found in the level of importance of yield, evapotranspiration, water-use efficiency, LSD classification of irrigation water-use efficiency values P<0.01 and/or P<0.05. Regression analysis values between irrigation water and yield of grafted and ungrafted eggplant in both cultivation seasons were found to be at a fairly good level ($0.80<R^2$). In addition, as an important finding, the regression analysis value of grafting in the second season was found to be at the highest level (R^2=91). In general, grafted eggplant plants were found to have had a higher total yield than the ungrafted plants. As the amount of irrigation water applied decreased, the yield also decreased. In the first season, the highest yields were recorded statistically in $FPRD_{100}$, I_{100} and $FPRD_{80}$ (45.26, 44.01 and 39.26 t ha^{-1}, respectively). Similarly, in the second season, the highest yields were obtained in I_{100} and $FPRD_{100}$ (50.97 and 48.96 t ha^{-1}, respectively) followed by $FPRD_{80}$ (48.96 t ha^{-1}). The advantages of the PRD technique over conventional and deficit irrigation have also been revealed. As a result of the research, it could be recommended that the cultivation of grafted eggplant seedlings is more suitable, and irrigation applications could be carried out using the PRD technique.

Keywords: Deficit irrigation, Yield response factor, Irrigation water use efficiency, Water-yield relations, Vegetable

1. Introduction

Precipitation distributions are changing worldwide with climate change, and irrigation is now more needed, including the areas where irrigation was previously unnecessary (Ouma et al. 2024). With the increase in the global population and industrialization, competition for freshwater is increasing gradually, which leads to the need for additional water resources (Ouma et al. 2024). Ensuring food security in a scenario where natural resources such as water are degraded seems to be a major challenge (Singh 2016). In addition, agriculture consumes about 70% of the available freshwater resources worldwide, and it is about 77% in Turkey (Anonymous 2022). The world population is estimated to be 9 billion and food production is expected to increase by 50% by 2050, (Mekonnen & Gerbens-Leenes 2020; Ungureanu et al. 2020). This population is expected to increase the demand for food, clothing and shelter, which are heavily dependent on water resources (Meena et al. 2023). In such a case, the water demand will increase even more and will put severe pressure on the agricultural sector, which uses the most water. Because plant production is one of the sectors most sensitive to and most affected by climate change and variability (Sikka et al. 2018).

Irrigation is compulsory for crop production, especially in arid and semi-arid climates. The reason for this is that the precipitation in the regions is irregular and insufficient. In order for irrigation to be effective, it is necessary to use correct irrigation planning and management. A successful irrigation strategy has three main issues such as (1) method, (2) time, and (3) amount. Correct and appropriate irrigation planning is essential because both excessive and insufficient irrigation damage the crop and lead to economic losses (Bhatnagar & Poonia 2018). In the correct and appropriate irrigation management; the variables of crop type, evaporation-transpiration, crop growth stage, climate, effective precipitation, soil water, etc. are very effective (Ouma et al. 2024).

Irrigation has some benefits such as reducing plant water stress, increasing yield, and helping to grow more than one crop across the year as the production is not dependent on seasons and precipitation (Zafar et al. 2020). Under conditions where water is required for crop production, growers need to manage the irrigation process very accurately. For example, in cases where water is insufficient, reducing water in each application and/or extending the irrigation interval to reduce the number of irrigations could be a solution. The irrigation mentioned so far is the conventional deficit irrigation strategy that has been applied traditionally. However, for the conventional deficit irrigation strategy to be used effectively, farmers must know in advance the critical-sensitive periods when plants need water (Kirda et al. 2004). On the other hand, another and relatively new type of irrigation applied without the need to know in advance the critical-sensitive periods when plants need water is the partial root drying (PRD) technique (Kirda et al. 2004). The PRD technique increases the efficiency of irrigation water use without reducing efficiency, and this is a very important achievement. This success has been achieved in many studies (Dry et al. 1995; Dry & Loveys 1998; Kang et al. 2000; Kang et al. 2001; Kang et al. 2002; Sonawane & Shrivastava 2022; Kaman et al. 2022; Kaman et al. 2023a; Kaman et al. 2023b; Kaman et al. 2023c). As can be understood from these studies, the PRD technique has been used for many plant species and varieties in the last 10 to 20 years. However, the PRD technique has not yet been examined in the cultivation of grafted and/or ungrafted eggplants.

Cantürk et al. (2023), Darko et al. (2019), Al-Hadidi & Sweity (2022) and Diaz-Perez & Eaton (2015) have highlighted the contribution of deficit irrigation to acceptable yield and quality in eggplant crops and water saving. Bozkurt Çolak (2019) reported that there are very few studies conducted to estimate the optimal amount of water for eggplant plants under deficit irrigation. According to the results of the few available studies in the literature, water use efficiency could be increased under reduced irrigation in eggplant cultivation (Bozkurt Çolak 2019).

Eggplant (*Solanum melongena* L.), which is one of the vegetables from the Solanaceae family, is a vegetable widely and traditionally produced in tropical, subtropical, and Mediterranean countries (Howladar 2018; Mokabel et al. 2022). 59.3 million tons of eggplant are produced worldwide (FAO 2024). In Turkey, eggplant constitutes about 1 million tons of 31.8 million tons of total vegetable production in Turkey in 2023, and has a share of 2.6% of the total production (TUIK 2024).

An important reason why grafted plants perform better than ungrafted plants has been attributed to the root system of grafted plants, which can go deeper by developing roots (Ibrahim et al. 2014; López-Marín et al. 2017). Different researchers have reported that grafting in pumpkin and eggplant plants can increase the WUE value due to an increase in the net CO_2 assimilation rate and/or a decrease in stomatal conductivity and transpiration rate, as reported for grafted eggplant (Khah et al. 2011; Al-Harbi et al. 2018). While the demand for grafted eggplant seedlings is increasing rapidly, research has focused on the effects of rootstock/scion combinations on plant performance in terms of yield and fruit quality (Sabatinoa et al. 2018). In this context, the yield, obvious quality characteristics and chemical composition of fruits obtained from grafted plants should remain equal or improved compared to nongrafted plants (Sabatinoa et al. 2018). According to Gisbert et al. (2011), Moncada et al. (2013), Maršič et al. (2014) and Sabatino et al. (2016), grafting can affect yield and fruit quality in eggplant. On the other hand, research on how greenhouse evaporation and microclimates affect evapotranspiration is needed for greenhouse water management and environmental control (Wang et al. 2024).

This study examined some potential reactions of grafted and ungrafted eggplant plants under the conventional and deficit irrigation and PRD techniques. Within the scope of the research, many observations and measurements were made regarding the growth, quality criteria, yield, yield components, water-use efficiency (WUE), irrigation water-use efficiency (IWUE) and yield-response factor (ky) of eggplant to determine the reactions of grafted and ungrafted eggplant plants under different irrigation applications.

2. Material and Methods

2.1. Climate and soil characteristics of the study site

The experiment was conducted during two spring growing seasons in 2019 (Season 1) and 2020 (Season 2) at the research fields of Akdeniz University, Faculty of Agriculture (30° 38' 30″ - 30° 39′ 45″ East, 36° 53′ 15″ - 36° 54′ 15″ North, 54 m above sea level), Antalya, Turkey. The study was carried out under completely controlled conditions in accordance with the growing season. The greenhouse was designed with a size of 16×60 m, which is widely used in Turkey and is established in a north-south direction.

The Mediterranean climate prevails in the study area Antalya. The average annual temperature is 18.0 °C, the relative humidity 63%, total precipitation is 1063.5 mm and total evaporation is 1886.3 mm (Anonymous 2000).

The soil type of the research area is the Gölbaşı series. The Gölbaşı series, which is developed on massive travertines, is included in the Entisol ordo because they are young soils that do not show much profile development. All the profiles of the soils of this series, which have an AC horizon and are very young, have a clay-tin texture. They are located in almost flat and almost flat topographies (Sarı et al. 1993). Analysis of spoiled and unspoiled soil samples taken from different parts of the experimental area were analyzed for the physical properties of the soil (Table 1). Based on these values, the greenhouse soil is perfectly suitable as a growing medium for eggplant.

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

2.2. Plant material

The Korsika F1 eggplant variety, whose production is widespread throughout Turkey and around Antalya province, where most greenhouse production takes place, was used as the plant material in the research, and the eggplant plants were grafted on the AGR703 rootstock. AGR703 rootstock is a variety with a strong root structure, high root development at a low rhizosphere temperature and very good rootstock-scion. The effective root depth of the eggplant plant is known to be 30-60 cm. Cultural practices such as fertilization and spraying of eggplant plants were carried out according to standard practices.

2.3. The drip irrigation system, plot sizes and experimental treatments

Irrigation and fertilization were conducted using a drip irrigation system with a 2 L h^{-1} dripper flow rate. Soil preparation (leveling, deep ploughing) was completed before planting. In the area where the research was conducted, soil preparation operations were carried out in a manner like farmer practices in the region. A completely randomized block experimental design, comprising irrigation treatments with three replicates, was used. Replicated sub-plots of each irrigation treatment were 4×2.4 m (9.6 m^2) in size and had 3 rows of 8 plants, with 0.8 m row spacing. The plant spacing in rows was 0.5 m.

The planting dates were 05 February and 07 February in 2019 and 2020, respectively. After the seedlings were planted in the greenhouse, sap water was given until the plants began to take root in the soil. Irrigation and fertilizer applications were carried out with a drip irrigation system with a 2 L h^{-1} dripper flow rate. The irrigation water applied was measured with a flow meter, installed in the water delivery unit of the irrigation system, which was designed for independent control of water delivery to each irrigation treatment. The water delivery unit had both mesh and sand filters for preventing dripper clogging. While irrigation was applied once a week after planting the seedlings, the number of irrigations increased to two per week with the increase in evaporation parallel to the increase in air temperatures. The last harvests were made on 28 June and 27 July, respectively, in 2019 and 2020. The amount of irrigation water 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}.

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

2.4. Irrigation water

We had used fixed irrigation interval, seven days until midseason, then two irrigations were applied weekly, at 3- and 4-day intervals. By doing so, irrigation water applied was limited to a maximum quantity of 6 L per plant, which prevented deep percolation (Kirda et al. 2004). Firstly, with the planting of seedlings, water was applied to each plant in equal amounts until rooting. Afterwards, irrigation water was calculated using the evaporation amounts from the evaporation container during the irrigation interval. A Class-A Evaporation Pan located in the center of the greenhouse was used to estimate irrigation water requirement (I, mm) for I_{100} using the Equation (1):

$$I = K \times Ep \tag{1}$$

Where; K is a coefficient comprising plant coverage, wetted area (diameter of 45–50 cm) and pan coefficient; Ep is cumulative evaporation (mm) measured during the allowed irrigation interval. K was allowed to change from 0.30 to 1.27 as the season progressed.

Table 2 - Irrigation treatments

Irrigation treatments	*Description*
	For conventional and deficit irrigation (I)
I_{100}	Irrigation water amount was applied uniformly on the two halves of plant root-zone (CONTROL).
I_{80}	Received 20% less water, compared to I100 irrigation.
I_{60}	Received 40% less water, compared to I100 irrigation.
I_{40}	Received 60% less water, compared to I100 irrigation.
	For fixed-partial root drying irrigation (FPRD)
$FPRD_{100}$	Received 100% water, compared to I100 irrigation; only one half of the plant root zone was relatively irrigated.
$FPRD_{80}$	Received 20% less water, compared to I100 irrigation; only one half of the plant root zone was relatively irrigated.
$FPRD_{60}$	Received 40% less water, compared to I100 irrigation; only one half of the plant root zone was relatively irrigated.
$FPRD_{40}$	Received 60% less water, compared to I100 irrigation; only one half of the plant root zone was relatively irrigated.

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

Plant evapotranspiration (ET, mm) was determined based on the water-budget using the following Equation (2):

$$ET = I \pm \Delta S \tag{2}$$

Where; I is the amount of irrigation water applied (mm); ΔS is 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 water-use efficiency (WUE, kg m^{-3}) to irrigation regime was determined using the following Equation (3):

$$WUE = \frac{Y}{ET} \tag{3}$$

Where; Y is yield (kg da^{-1}); ET is evapotranspiration (mm).

The irrigation water-use efficiency (IWUE, kg m^{-3}) to irrigation regime was determined using the following Equation (4):

$$IWUE = \frac{Y}{I} \tag{4}$$

Where; Y is the yield (kg da^{-1}); I is 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 (5) proposed by Doorenbos & Kassam (1979) and Stewart et al. (1977):

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

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

2.6. Measurement and observation of fruit quality and other parameters

In addition to those explained above, total yield, mean fruit weight, fruit width, fruit length, biomass, plant height observations and measurements were made. Fruit width and length were measured with a caliper. Biomass and plant height measurements were made by cutting the plants from the soil surface at the end of the season. In addition, plant height measurements were made once a week throughout the growing season. Total soluble solids content (SSC, %), pH, fruit color (L*), fruit color (a*), fruit color (b*) measurements were also made in the fruits. Total SSC amount in the juices obtained from the harvested eggplant fruits with a juicer was determined with a digital refractometer (%). pH values were measured in the juices obtained with a juicer. Colour values were measured with a Minolta CR400 colour chromameter, SSC digital refractometer (Siomas et al. 2002; Madeira et al. 2003).

2.7. Statistical analysis

A completely randomized block experimental design was employed, comprising irrigation treatments with three replicates. The plants from the beginning and end of the rows were excluded from the measurement to prevent the plant edge effect. A one-way analysis of variance (ANOVA) was performed using the SAS package program. The significance of the differences in the means of the different treatments were tested at P<0.01 and P<0.05 significance levels. The LSD multiple comparison test was used to investigate which of the treatment means differed in cases where the ANOVA results showed a significant difference in the means.

3. Results

3.1. Evaporation from Class-A Pan and amount of irrigation water

As expected, the amount of irrigation water also increased in parallel with the increase in the amount of evaporation for both seasons of study (Figure 1). In the first (2019) season of the study, irrigation water application was applied a total of 35 times in total depending on the evaporation amounts measured in the Class-A evaporation. In the second (2020) season, irrigation water was applied 44 times in total. However, since the process in the second season was longer, the number and amount of irrigations was naturally higher (Figure 1).

3.2. Yield, evapotranspiration, water-use efficiency, irrigation water-use efficiency

The amount of irrigation water was applied between 148.45 and 365.48 mm in the first season, and between 245.61 and 584.84 mm in the second season (Tables 3 and 4). Depending on the amount of irrigation water application, statistical differences (at P<0.01 and/or P<0.05) were found in the yield values. Similarly, evapotranspiration (ET), water use efficiency, irrigation water use efficiency values were also found to be statistically significant (Tables 3 and 4).

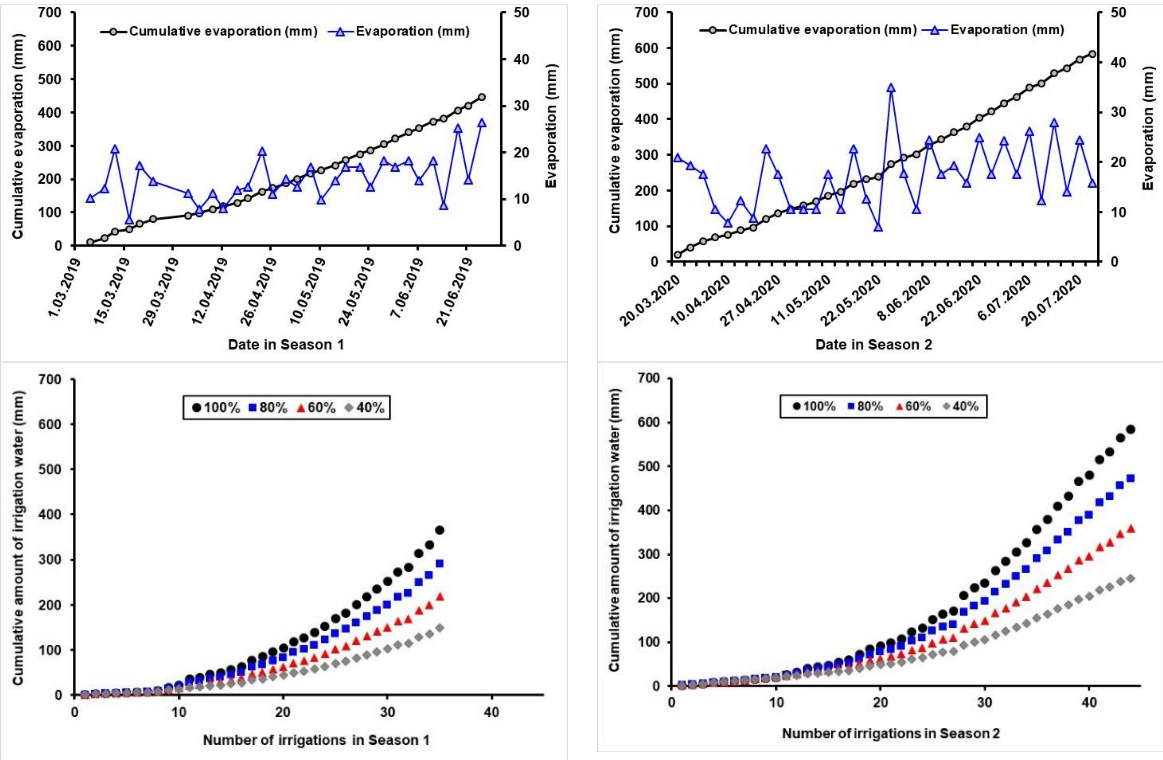

Figure 1 - Evaporation (mm) from Class-A Pan in the greenhouse and cumulative amount of irrigation water (mm) under 100%, 80%, 60% and 40% for ungrafted-grafted eggplant

Table 3 - Irrigation water, yield, ET, WUE, and IWUE in Season 1

Treatments		*I (mm)*	*Yield (t ha^{-1})*	*ET (mm)*	*WUE (kg m^{-3})*	*IWUE (kg m^{-3})*
I_{100}		365.48	44.01 a	390.11 a	11.28	12.04
I_{80}		291.36	31.29 bc	316.57 c	9.91	10.74
I_{60}		219.02	27.72 cd	256.71 d	10.80	12.65
I_{40}		148.45	21.30 d	187.40 f	11.40	14.35
$FPRD_{100}$		365.48	45.26 a	392.98 a	11.52	12.38
$FPRD_{80}$		291.36	39.26 ab	333.43 b	11.78	13.47
$FPRD_{60}$		219.02	30.78 bcd	261.63 d	11.75	14.05
$FPRD_{40}$		148.45	22.93 cd	194.60 e	11.79	15.44
Significance Level of Irrigation (I)		-	**	**	ns	ns
Ungrafted		-	31.30	291.24	10.72	12.41
Grafted		-	34.33	292.13	11.84	13.88
Significance Level of Graft (G)		-	ns	ns	ns	ns
I_{100}	Ungrafted	365.48	40.92	389.01 a	10.52 bd	11.20 cd
	Grafted	365.48	47.10	391.22 a	12.04 ad	12.89 bd
I_{80}	Ungrafted	291.36	27.86	322.76 c	8.63 cd	9.56 d
	Grafted	291.36	34.72	310.38 d	11.19 bd	11.92 bd
I_{60}	Ungrafted	219.02	27.49	260.89 f	10.54 bd	12.55 bd
	Grafted	219.02	27.95	252.54 g	11.07 bd	12.76 bd
I_{40}	Ungrafted	148.45	24.60	184.11 ı	13.36 ab	16.57 ab
	Grafted	148.45	17.99	190.70 hı	9.43 bd	12.12 bd
$FPRD_{100}$	Ungrafted	365.48	45.49	394.91 a	11.52 ad	12.45 bd
	Grafted	365.48	45.03	391.05 a	11.52 ad	12.32 bd
$FPRD_{80}$	Ungrafted	291.36	41.12	329.04 c	12.50 ac	14.11 bd
	Grafted	291.36	37.40	337.82 b	11.07 bd	12.83 bd
$FPRD_{60}$	Ungrafted	219.02	28.10	254.20 fg	11.05 bd	12.83 bd
	Grafted	219.02	33.47	269.06 e	12.44 ac	15.28 bc
$FPRD_{40}$	Ungrafted	148.45	14.83	194.98 h	7.61 d	9.99 d
	Grafted	148.45	31.03	194.23 h	15.97 a	20.90 a
Significance Level of IxG		-	ns	**	*	*

I=Irrigation water (mm); Y=Yield (t ha^{-1}); ET=Evapotranspiration (mm); WUE=Water-use efficiency (kg m^{-3}) and IWUE=Irrigation water-use efficiency (kg m^{-3}); Means with different letters in the same column were significantly different; *: (P<0.05), **: (P<0.01), ns: non-significant

In general, grafted plants had a higher yield than ungrafted plants (Table 4). In other words, the situation was similar in all irrigation treatments and it was revealed that grafting had an increasing effect on yield. The statistical change in yield values is very significant (P<0.01) for the irrigation levels (100%, 80%, 60%, and 40%). The differences between irrigation×grafting (P<0.01) and irrigation×grafting (I×G) correlations were not statistically significant (Tables 3 and 4). However, grafting was also very important (P<0.01) in the second season (Table 4). In the first season, I_{100}, $FPRD_{100}$, and $FPRD_{80}$ treatments had the highest yield value and I_{40} had the lowest yield value (Table 3). In the second season, I_{100} and $FPRD_{100}$ treatments had the highest yield value, and I_{40} and $FPRD_{40}$ had the lowest yield value (Table 4). As the amount of irrigation water increased, the yield values also tended to increase (Tables 3 and 4).

It can be said that grafting, together with irrigation water, also increases yield. Similar results were found for the mass values (Tables 3 and 4). In addition, the differences between the irrigation×grafting (I×G) correlations for mass values were also found to be statistically significant (P<0.01 and P<0.05) (Tables 3 and 4). The differences between the irrigation×grafting (I×G) correlations were found to be statistically significant (P<0.01 and P<0.05). As with irrigation water, the increase in the amount of mass along with the increase in yield values also tended to increase (Tables 3 and 4). Grafting, together with the mass value, could be claimed to have increased yield. The correlation of irrigation×grafting (I×G) in the first season (Table 3) and the change between grafting and irrigation levels (100%, 80%, 60%, and 40%) in the second season (Table 4) were found to be statistically very significant (P<0.01) for WUE. The correlation between irrigation× grafting (I×G) was found to be statistically significant (P<0.01). Similar to the WUE values, the irrigation×grafting (I×G) correlation was found to be important for IWUE in the first season (Table 3) (P<0.05), and grafting was found to be very important in the second season (Table 4) (P<0.01).

Table 4 - Irrigation water, yield, ET, WUE, and IWUE in Season 2

Treatments		*I (mm)*	*Yield (t ha^{-1})*	*ET (mm)*	*WUE (kg m^{-3})*	*IWUE (kg m^{-3})*
I_{100}		584.84	50.97 a	657.70 a	7.75 a	8.71
I_{80}		472.12	32.48 cd	546.08 b	5.96 bcd	6.88
I_{60}		358.73	30.07 d	427.77 d	7.06 abc	8.38
I_{40}		245.61	17.52 e	321.38 f	5.45 cd	7.13
$FPRD_{100}$		584.84	48.96 ab	657.51 a	7.45 ab	8.37
$FPRD_{80}$		472.12	40.88 bc	546.23 b	7.48 ab	8.66
$FPRD_{60}$		358.73	30.57 d	435.84 c	7.00 abc	8.52
$FPRD_{40}$		245.61	15.74 e	332.86 e	4.73 d	6.41
Significance Level of Irrigation (I)		-	**	**	**	ns
Ungrafted		-	29.87 b	491.26	5.88 b	7.02 b
Grafted		-	36.93 a	490.08	7.34 a	8.75 a
Significance Level of Graft (G)		-	**	Ns	**	**
I_{100}	Ungrafted	584.84	46.41	657.50 a	7.06	7.94
	Grafted	584.84	55.52	657.90 a	8.44	9.49
I_{80}	Ungrafted	472.12	25.86	551.49 b	4.69	5.48
	Grafted	472.12	39.09	540.66 b	7.23	8.28
I_{60}	Ungrafted	358.73	21.49	433.74 cd	4.95	5.99
	Grafted	358.73	38.66	421.80 e	9.17	10.78
I_{40}	Ungrafted	245.61	16.23	323.26 g	5.02	6.61
	Grafted	245.61	18.81	319.51 g	5.89	7.66
$FPRD_{100}$	Ungrafted	584.84	47.33	656.57 a	7.21	8.09
	Grafted	584.84	50.58	658.46 a	7.68	8.65
$FPRD_{80}$	Ungrafted	472.12	40.20	549.54 b	7.31	8.51
	Grafted	472.12	41.56	542.92 b	7.66	8.80
$FPRD_{60}$	Ungrafted	358.73	25.69	429.87 de	5.98	7.16
	Grafted	358.73	35.45	441.82 c	8.02	9.88
$FPRD_{40}$	Ungrafted	245.61	15.73	328.12 fg	4.79	6.40
	Grafted	245.61	15.76	337.60 f	4.67	6.42
Significance Level of IxG		-	ns	*	ns	ns

I=Irrigation water (mm); Y=Yield (t ha^{-1}); ET=Evapotranspiration (mm); WUE=Water-use efficiency (kg m^{-3}) and IWUE=Irrigation water-use efficiency (kg m^{-3}); Means with different letters in the same column were significantly different; *: (P<0.05), **: (P<0.01), ns: non-significant.

3.3. Regression analysis between water and yield

Regression analysis values between irrigation water and yield of grafted and ungrafted eggplant in both cultivation seasons were found to be at a fairly good level (R^2>80) (Figure 2). However, as an important finding, the regression analysis value of grafting in the second season was found to be at the highest level with R^2=91 (Figure 2).

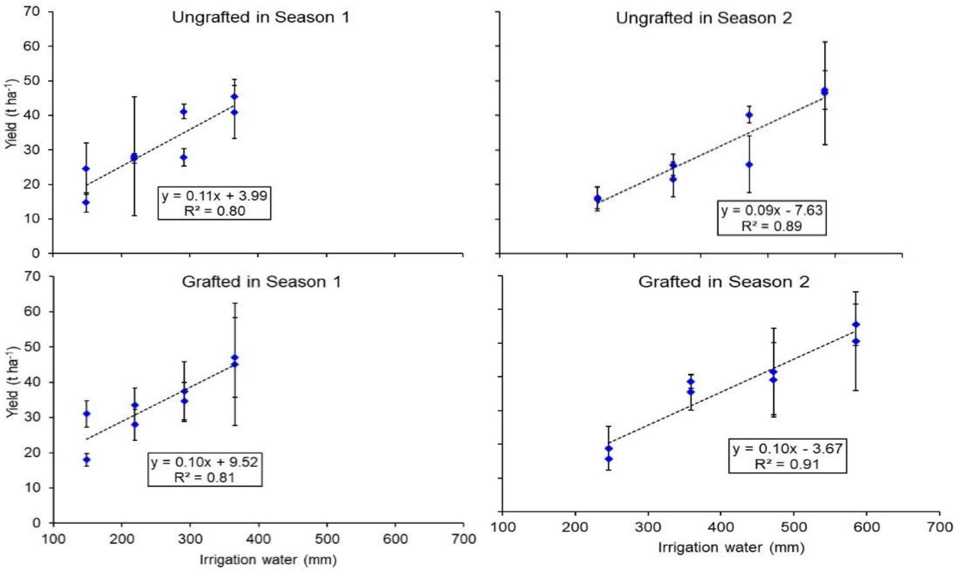

Figure 2 - Correlations between irrigation water and yield on ungrafted-grafted eggplant (The bars show standard deviation)

Similar to the regression analysis results between irrigation water and yield (Figure 2), the regression analysis values between evapotranspiration and yield were calculated at a good level (R^2>80) (Figure 3). As an important result, the regression analysis value of grafting in the second season occurred at the highest level with R^2=89 (Figure 3). Regression analysis between both irrigation water and yield and evapotranspiration and yield revealed an increasing correlation (Figures 2 and 3). In particular, despite the increase in the amount of irrigation water, there has been no decrease in yield values. This reveals that the amount of irrigation water is applied correctly and under appropriate conditions. In general, the fact that the R^2 values are greater than 0.80 in the regression analysis reveals that irrigation is managed very well and correctly (Figures 2 and 3). It can also be concluded that grafting, together with irrigation management, is very valuable in the eggplant plant.

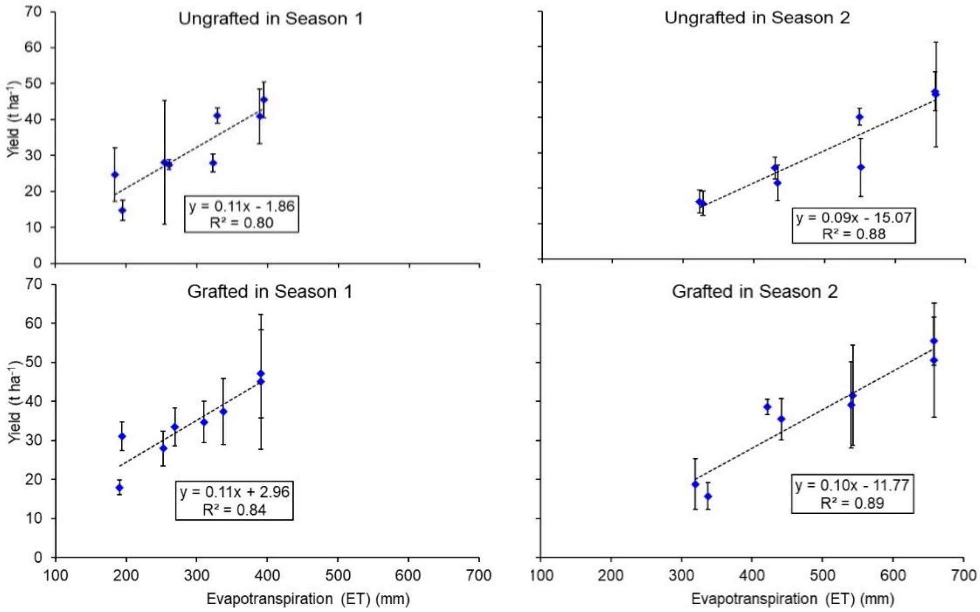

Figure 3 - Correlations between evapotranspiration (ET) and yield on ungrafted-grafted eggplant (The bars show standard deviation)

3.4. Yield response factor

Yield response indicates a decrease in yield in response to a unit decrease in evapotranspiration. Yield response graphs have been prepared as an indicator of the effect of a proportional decrease in plant water consumption on a proportional decrease in ungrafted eggplant yield (Figure 4). In the regression analysis, ky values were found by using seasonal plant water consumption and yield values. In the first season, the ky values changed between 0.68 and 1.87, and in the second season between 0.80 and 2.70 (Figure 4). In response to the proportional decrease in plant water consumption, decreases have also occurred in the yield of ungrafted and grafted eggplants. However, it can be said that the most significant results were obtained in grafted eggplant and FPRD irrigation.

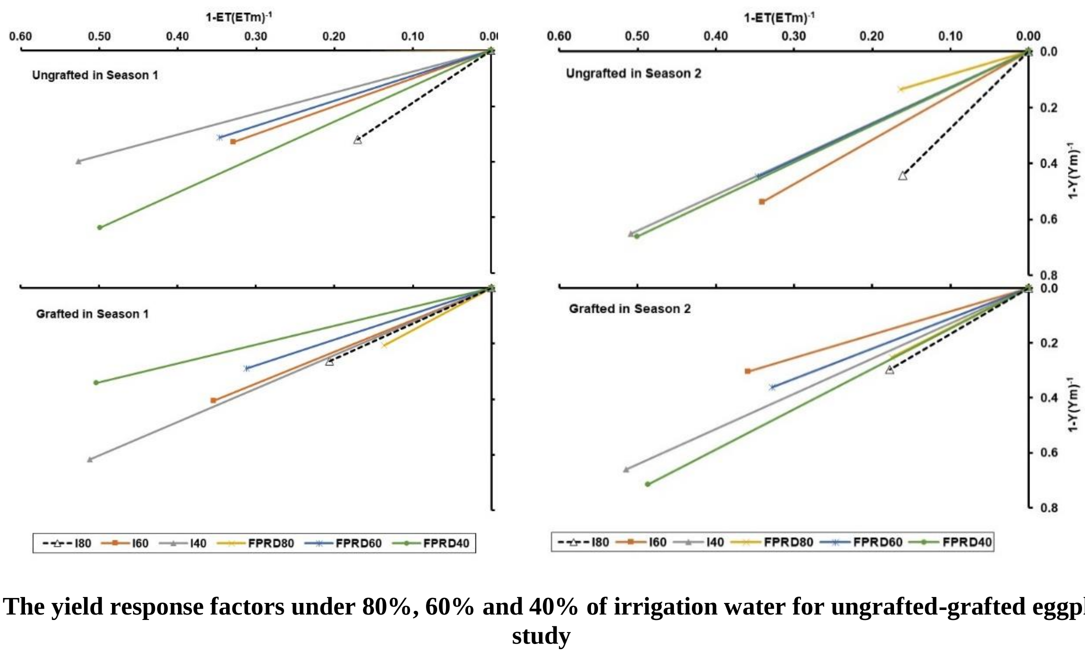

Figure 4 - The yield response factors under 80%, 60% and 40% of irrigation water for ungrafted-grafted eggplant in the study

3.5. Yield components, biomass and plant height

The statistical analysis results of the yield-related parameters such as total yield per plant, average fruit weight, fruit width, and fruit length, as well as dry biomass and plant height values are given in Tables 5 and 6. The biomass and plant height values in the tables were taken on the last day of the research. In addition, plant height changes were also monitored during the season (Figure 5). All parameters regarding the yield were negatively affected by water stress in general.

Table 5 - Total yield, mean fruit weight, fruit width, fruit length, biomass, plant height in Season 1

Treatments		*Total fruit yield (g plant^{-1})*	*Mean fruit weight (g fruit^{-1})*	*Fruit width (mm fruit^{-1})*	*Fruit length (mm fruit^{-1})*	*Biomass (g plant^{-1})*	*Plant height (at the end of the season) (cm plant^{-1})*
I_{100}		1760.44 a	153.10 ab	51.63	15.35 ab	88.69 b	108.25 ab
I_{80}		1251.64 bc	146.72 bc	53.05	14.84 b	66.35 c	94.56 c
I_{60}		1108.68 cd	147.51 bc	52.85	14.56 b	56.80 cd	83.92 ce
I_{40}		851.85 d	135.23 cd	52.30	13.21 c	44.25 e	73.19 e
$FPRD_{100}$		1810.31 a	161.57 a	51.26	15.84 a	115.06 a	111.25 a
$FPRD_{80}$		1570.35 ab	145.74 bc	51.05	14.78 b	90.87 b	96.67 bc
$FPRD_{60}$		1231.30 bd	143.75 bc	52.12	14.67 b	51.92 de	88.58 cd
$FPRD_{40}$		917.08 cd	129.70 d	50.24	13.64 c	48.31 de	76.31 de
Significance Level of Irrigation (I)		**	**	ns	**	**	**
Ungrafted		1252.04	149.90 a	52.95 a	14.48	68.86	87.51 b
Grafted		1373.38	140.93 b	50.68 b	14.74	71.70	95.67 a
Significance Level of Graft (G)		ns	*	**	ns	ns	*
I_{100}	Ungrafted	1636.85	162.84 ab	53.07 ad	15.36 ab	81.73 cd	105.78
	Grafted	1884.02	143.37 bd	50.19 df	15.35 ab	95.65 bc	110.72
I_{80}	Ungrafted	1114.43	147.44 bd	53.88 ac	14.63 ac	71.84 de	91.67
	Grafted	1388.86	146.00 bd	52.22 bf	15.06 ac	60.85 ef	97.44
I_{60}	Ungrafted	1099.52	138.74 ce	52.62 ae	13.98 cf	59.44 ef	82.22
	Grafted	1117.84	156.28 ac	53.09 ad	15.13 ac	54.15 fg	85.61
I_{40}	Ungrafted	984.18	149.64 bd	55.89 a	13.27 df	49.82 fh	69.56
	Grafted	719.52	120.81 e	48.72 f	13.15 ef	38.68 h	76.83
$FPRD_{100}$	Ungrafted	1819.44	170.20 a	51.83 bf	15.84 a	108.26 ab	99.56
	Grafted	1801.18	152.94 ad	50.69 cf	15.83 a	121.85 a	122.94
$FPRD_{80}$	Ungrafted	1644.89	156.30 ac	52.89 ad	15.56 ab	90.85 c	95.11
	Grafted	1495.81	135.18 de	49.22 ef	13.99 cf	90.89 c	98.22
$FPRD_{60}$	Ungrafted	1123.85	152.51 ad	54.67 ab	14.35 be	43.11 gh	87.44
	Grafted	1338.75	134.98 de	49.57 df	14.98 ac	60.72 ef	89.72
$FPRD_{40}$	Ungrafted	593.13	121.56 e	48.74 f	12.83 f	45.79 fh	68.72
	Grafted	1241.04	137.84 ce	51.73 bf	14.45 bd	50.84 fh	83.89
Significance Level of IxG		ns	**	**	*	*	ns

Means with different letters in the same column were significantly different; *: ($P<0.05$), **: ($P<0.01$), ns: non-significant

For the irrigation levels in the first season (100%, 80%, 60%, and 40%); the statistical change in the values of total yield per plant, average fruit weight, fruit length, biomass, and plant length were found to be very significant ($P<0.01$) (Table 5). For grafting, the average fruit weight and plant height were significant ($P<0.05$), while the fruit width was very significant ($P<0.01$). In the irrigation×grafting (I×G) correlation, mean fruit weight and fruit width were highly significant ($P<0.01$), while fruit length and biomass were found to be significant ($P<0.05$).

In the statistical analysis of irrigation levels in the second season (100%, 80%, 60%, and 40%); total yield per plant, average fruit weight, fruit length, biomass, and plant length were found to be highly significant ($P<0.01$), while fruit width was found to be significant ($P<0.05$). For grafting, the total yield per plant and fruit size were highly significant ($P<0.01$), and plant size was significant ($P<0.05$). In the irrigation×grafting (I×G) correlation, only the average fruit weight was found to be significant ($P<0.05$).

In both seasons, the plant height increased gradually at all deficit irrigation levels of ungrafted and grafted eggplants (Figure 5). In the first season, the average height of ungrafted eggplants was 60.32 cm on ungrafted eggplant, the lowest was 20.61 cm, and the highest was 105.78 cm on I100. The average size of grafted eggplant was 64.68 cm, the lowest was 27.28 cm, and the highest was 122.94 cm on $FPRD_{100}$. In the second season, the average was measured at 63.87 cm in grafted eggplant, the lowest was measured as 12.83 cm, and the highest was measured as 114.11 cm in I_{100}. On the grafted eggplant, the average was measured as 69.18 cm, the lowest was measured as 19.33 cm, and the highest was measured as 124.22 cm in the I_{100} treatment.

Table 6 - Total yield, mean fruit weight, fruit width, fruit length, biomass, plant height in Season 2

Treatments		*Total fruit yield (g plant^{-1})*	*Mean fruit weight (g fruit^{-1})*	*Fruit width (mm fruit^{-1})*	*Fruit length (mm fruit^{-1})*	*Biomass (g plant^{-1})*	*Plant height (at the end of the season) (cm plant^{-1})*
I_{100}		2038.67 a	156.31 a	52.01 a	15.58 ab	130.09 a	119.17 a
I_{80}		1299.00 cd	143.85 bc	50.98 ab	14.88 cd	74.52 cd	101.11 bc
I_{60}		1202.88 d	136.35 c	51.79 a	14.42 d	61.75 de	92.83 cd
I_{40}		700.83 e	123.74 d	48.99 b	13.74 e	44.45 f	87.39 d
$FPRD_{100}$		1958.29 ab	154.94 a	52.09 a	15.74 a	109.33 b	114.83 a
$FPRD_{80}$		1635.17 bc	148.25 ab	51.65 a	15.42 ac	81.67 c	107.61 ab
$FPRD_{60}$		1222.92 d	148.13 ab	50.87 ab	15.05 bc	49.03 ef	97.83 bd
$FPRD_{40}$		629.71 e	120.63 d	49.24 b	13.79 e	48.06 ef	86.39 d
Significance Level of Irrigation (I)		**	**	*	**	**	**
Ungrafted		1194.66 b	140.967	51.06	14.62 b	72.19	97.58 b
Grafted		1477.21 a	142.083	50.84	15.03 a	77.54	104.21 a
Significance Level of Graft (G)		**	ns	ns	**	ns	*
I_{100}	Ungrafted	1856.50	151.94 ac	52.18	15.24	131.18	114.11
	Grafted	2220.83	160.68 ab	51.84	15.92	128.99	124.22
I_{80}	Ungrafted	1034.33	144.96 cd	50.78	14.50	78.02	98.56
	Grafted	1563.67	142.73 cd	51.18	15.27	71.02	103.67
I_{60}	Ungrafted	859.42	135.75 de	52.58	14.12	57.07	85.33
	Grafted	1546.33	136.95 de	50.99	14.72	66.44	100.33
I_{40}	Ungrafted	649.17	127.72 ef	48.69	13.69	43.00	85.33
	Grafted	752.50	119.76 fg	49.30	13.78	45.91	89.44
$FPRD_{100}$	Ungrafted	1893.25	146.22 cd	51.50	15.27	98.05	110.89
	Grafted	2023.33	163.67 a	52.68	16.21	120.61	118.78
$FPRD_{80}$	Ungrafted	1607.83	143.68 cd	51.58	15.33	83.51	102.56
	Grafted	1662.50	152.82 ac	51.73	15.51	79.84	112.67
$FPRD_{60}$	Ungrafted	1027.67	150.31 bc	51.28	14.93	43.15	97.67
	Grafted	1418.17	145.94 cd	50.45	15.16	54.92	98.00
$FPRD_{40}$	Ungrafted	629.08	127.15 eg	49.93	13.89	43.56	86.22
	Grafted	630.33	114.11 g	48.55	13.70	52.56	86.56
Significance Level of IxG		ns	*	ns	ns	ns	ns

Means with different letters in the same column were significantly different; *: (P<0.05), **: (P<0.01), ns: non-significant

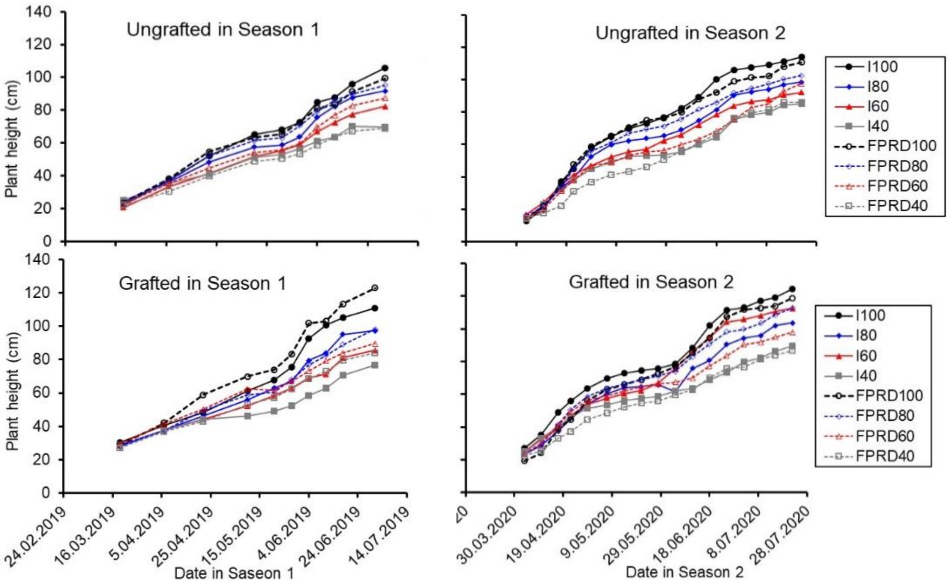

Figure 5 - Variation of plant height with deficit irrigation levels through the growing seasons

3.6. SSC, pH and fruit outer color

The statistical change in irrigation levels in the first season (100%, 80%, 60%, and 40%) and only the pH values for grafting were found to be very significant (P<0.01) (Table 7). In the statistical analysis of the correlation between irrigation levels (100%, 80%, 60%, and 40%) and irrigation×grafting (I×G) in the second season, only pH was highly significant (P<0.01) (Table 8). In the grafting, pH, and fruit color a* were found to be significant (P<0.05).

Table 7 - SSC, pH, fruit color (L*), fruit color (a*), fruit color (b*) in Season 1

Treatments		*SSC*	*pH*	*L**	*a**	*b**
I_{100}		5.38	8.97 cb	36.59	5.20	0.87
I_{80}		5.02	8.81 cb	36.20	4.59	0.77
I_{60}		5.83	8.67 cb	36.76	5.27	0.75
I_{40}		5.72	10.14 a	36.32	4.97	0.75
$FPRD_{100}$		5.43	8.29 c	36.06	5.08	0.80
$FPRD_{80}$		5.05	9.32 b	36.28	5.12	0.81
$FPRD_{60}$		5.47	8.94 cb	36.49	5.70	0.83
$FPRD_{40}$		5.43	8.92 cb	36.65	5.47	0.83
Significance Level of Irrigation (I)		ns	**	ns	ns	ns
Ungrafted		5.45	8.76 b	36.42	5.22	0.79
Grafted		5.37	9.26 a	36.42	5.13	0.81
Significance Level of Graft (G)		ns	**	ns	ns	ns
I_{100}	Ungrafted	5.50	9.02	36.42	5.42	0.82
	Grafted	5.27	8.92	36.76	4.99	0.92
I_{80}	Ungrafted	5.20	8.56	36.06	4.60	0.57
	Grafted	4.83	9.06	36.34	4.58	0.98
I_{60}	Ungrafted	5.77	8.66	36.82	5.56	0.88
	Grafted	5.90	8.68	36.70	4.99	0.62
I_{40}	Ungrafted	5.90	9.74	36.79	5.44	0.88
	Grafted	5.53	10.54	35.86	4.50	0.61
$FPRD_{100}$	Ungrafted	5.57	7.87	35.70	4.84	0.79
	Grafted	5.30	8.71	36.42	5.33	0.81
$FPRD_{80}$	Ungrafted	5.10	9.15	36.30	4.74	0.73
	Grafted	5.00	9.48	36.27	5.50	0.89
$FPRD_{60}$	Ungrafted	5.53	8.80	36.77	5.78	0.89
	Grafted	5.40	9.09	36.20	5.63	0.77
$FPRD_{40}$	Ungrafted	5.17	8.24	36.46	5.40	0.79
	Grafted	5.70	9.60	36.84	5.54	0.86
Significance Level of IxG		ns	Ns	ns	ns	ns

Means with different letters in the same column were significantly different; *: (P<0.05), **: (P<0.01), ns: non-significant

Table 8 - SSC, pH, fruit color (L*), fruit color (a*), fruit color (b*) in Season 2

Treatments		*SSC*	*pH*	*L**	*a**	*b**
I_{100}		5.03	6.20 a	26.76	7.51	0.29
I_{80}		5.40	6.15 ab	26.67	7.26	0.28
I_{60}		5.15	6.20 a	26.57	6.81	0.25
I_{40}		5.70	6.11 b	26.68	6.62	0.22
$FPRD_{100}$		5.03	6.21 a	26.68	6.53	0.24
$FPRD_{80}$		5.38	6.18 a	26.58	6.57	0.21
$FPRD_{60}$		5.13	6.21 a	26.39	6.88	0.16
$FPRD_{40}$		5.00	6.10 b	26.32	6.61	0.17
Significance Level of Irrigation (I)		ns	**	ns	ns	ns
Ungrafted		5.27	6.19 s	26.65	7.05 a	0.23
Grafted		5.19	6.15 b	26.51	6.64 b	0.22
Significance Level of Graft (G)		ns	*	ns	*	ns
I_{100}	Ungrafted	5.10	6.19 ad	26.83	7.78	0.30
	Grafted	4.97	6.20 ad	26.69	7.23	0.28
I_{80}	Ungrafted	5.83	6.11 df	26.92	7.64	0.31
	Grafted	4.97	6.19 ad	26.43	6.87	0.24
I_{60}	Ungrafted	4.97	6.17 bd	26.65	6.80	0.21
	Grafted	5.33	6.23 ac	26.48	6.83	0.29
I_{40}	Ungrafted	5.60	6.20 ad	26.88	6.54	0.23
	Grafted	5.80	6.02 f	26.48	6.71	0.20
$FPRD_{100}$	Ungrafted	5.07	6.28 a	26.92	6.67	0.26
	Grafted	5.00	6.14 ce	26.44	6.39	0.23
$FPRD_{80}$	Ungrafted	5.30	6.24 ab	26.56	6.74	0.24
	Grafted	5.47	6.12 de	26.61	6.39	0.17
$FPRD_{60}$	Ungrafted	5.17	6.23 ac	26.25	7.34	0.15
	Grafted	5.10	6.18 bd	26.52	6.41	0.16
$FPRD_{40}$	Ungrafted	5.13	6.07 ef	26.18	6.89	0.18
	Grafted	4.87	6.13 de	26.45	6.33	0.17
Significance Level of IxG		ns	**	ns	ns	ns

Means with different letters in the same column were significantly different; *: (P<0.05), **: (P<0.01), ns: non-significant

4. Discussion

Soil and irrigation water test results performed at the beginning of the season are presented in Table 1, respectively. The EC (dS m^{-1}) values of the irrigation water at the beginning of the season were found to be suitable for eggplant irrigation as claimed by Machado & Serralheiro (2017). The pH of the irrigation water was also found suitable for the cultivation of eggplant (Okiror et al. 2017).

4.1. Evaporation from Class-A Pan and amount of irrigation water

The amount of irrigation water was recorded between 148.45 and 365.48 mm and between 245.61 and 584.84 mm in the first and second seasons respectively (Tables 3 and 4). Similarly, Ayas (2017) determined the amount of irrigation water required for eggplant cultivation to be between 85 mm and 464 mm, with mass values ranging between 170 mm and 472 mm. During the research, the amount of irrigation water also increased due the increasing evaporation values, the extension of days and plant growth (Figure 1). Similar results have been documented in many studies (e.g. Kirda et al. 2004; Topcu et al. 2007; Cantürk et al. 2023). This reveals that the research and especially the irrigation management have been carried out correctly.

4.2. Yield, evapotranspiration, water-use efficiency, irrigation water-use efficiency

As seen in Tables 3 and 4, it is an important result that the fruit mass values are higher than the irrigation water quantity values throughout the study, because in such a case it may mean that water is not wasted through ways such as surface flow, deep filtration, etc. Therefore, it is an indicator that irrigation has been managed well and that water has been used most effectively.

Depending on irrigation and grafting in the research; the results of ANOVA analysis regarding yield (Y), evapotranspiration (ET) water-use efficiency, and irrigation water-use efficiency values showed a significant change at the $P<0.01$ and/or $P<0.05$ level (Tables 3 and 4). When the grafted and ungrafted eggplant yields in the first season of the study are considered together, depending on the irrigation practices (Table 3), the $FPRD_{100}$ and $FPRD_{80}$ treatments gave similar results. In other words, the highest yield was obtained with less water. Although they had statistically the highest yield compared to the $FPRD_{100}$ and I_{100}, 2.8% more yield was obtained from the $FPRD_{100}$. This reveals the importance of partial-wetting irrigation. A similar result is found in the irrigation treatments producing the highest yield. The results of this research are consistent with previous research in literature. Ertek et al. (2006) found that there was a decrease in eggplant yield when the highest irrigation water was applied in the deficit irrigation study. This means that the amount of water should be optimized to avoid excessive irrigation conditions that may negatively affect crop yield in eggplant cultivation. In this study, the negativity that Ertek et al. (2006) highlighted was not experienced as no excessive irrigation was applied (Figure 1, Tables 3 and 4). In general, grafted plants have produced more yield than ungrafted plants. Grafting was very important for yield values, especially in the second season (Table 4) ($P<0.01$). The increase in yield of grafted eggplants is similar to that reported by Consentino et al. (2022).

Water stress also reduces the ability of plants to perform photosynthesis, which negatively affects their growth and production (Kumar et al. 2019). Semida et al. (2021) also reported that the increase in water stress reduced eggplant yield. This explains that the yield decreases due to an increase in water stress. The results of this research are consistent with the study conducted by Ayas (2017), which found that the yield of eggplant is significantly affected by the irrigation level applied. For example, the studies conducted by Kirda et al. (2004), Topcu et al. (2007), and Kirda et al. (2007) on other vegetables such as tomatoes and peppers, found consistent results with this study. Similarly, cucumbers under deficit irrigation, PRD techniques, and conventional irrigation (Kaman et al. 2022; Kaman et al. 2023a) and also strawberry plants experienced a decrease in yield (Kaman et al. 2023b; Kaman et al. 2023c) due to increased water stress.

In general, these studies also showed a change in yield values as a function of different amounts of irrigation water. The results obtained from this study are similar to the values given in the literature. However, the I_{100}, $FPRD_{100}$ and $FPRD_{80}$ treatments in the first season and the I_{100} and $FPRD_{100}$ treatments in the second season had the highest yield value (Table 3, Table 4). On the other hand, this study did not examine the irrigation levels such as 125% and 150%, and it was found that 80% and 100% irrigation levels gave quite good results. Regression analysis values between the irrigation water and yield of grafted and ungrafted eggplant in both growing seasons were found to be at a fairly good level ($R^2>80$) (Figure 2). However, as an important finding, the regression analysis value of grafting in the second season was found to be at the highest level with $R^2=91$ (Figure 2). The regression analysis between both irrigation water-yield and evapotranspiration-yield revealed an increasing correlation (Figures 2 and 3). In particular, despite the increase in the amount of irrigation water, there was no decrease in yield values. This reveals that the amount of irrigation water was correctly applied under appropriate conditions. In general, the fact that the R^2 values are greater than 0.80 in the regression analysis reveals that irrigation has been managed very well (Figures 2 and 3). It can also be concluded that grafting, together with irrigation management, is very important in eggplant cultivation. Canturk et al. (2023) reported that differences in the amount of water consumption during the cultivation season caused a significant difference in eggplant yield. Many studies have reported that there is a linear relationship between yield and seasonal evapotranspiration (Öktem et al. 2003; Bozkurt Çolak et al. 2018; Karam et al. 2011).

IWUE is an important indicator that shows how efficiently the plant uses the available water to produce a certain yield (Ouma et al. 2024). Similarly, WUE is another important parameter that shows the efficient use of available water. Since plants with water stress fade quicker than the normal conditions, plants under water stress have a higher IWUE (Rodan et al. 2020). In this study, the correlation of irrigation×grafting in the first season for WUE (Table 3) and the irrigation levels with grafting in the second season (Table 4) were found to be statistically very significant ($P<0.01$). In line with these research results, different researchers have reported that the grafting may increase WUE due to a decrease in stoma conductivity and transpiration rate (Khah et al. 2011; Al-Harbi et al. 2018). For IWUE, the irrigation×grafting correlation was found to be important in the first season ($P<0.05$) (Table 3), and grafting was found to be very important in the second season ($P<0.01$) (Table 4). The WUE and IWUE results of this study are generally consistent with the findings of Ouma et al. (2024) Rodan et al. (2020), Darko et al. (2019), Mohawesh (2016) and Wakchaure et al. (2020). In addition, the results of Ayas (2017), Bozkurt Çolak et al. (2017) and Al Ali et al. (2018) regarding IWUE values are similar to those of this research.

4.3. Yield response factor

The yield-response factor is another important parameter indicating a decrease in yield in response to a unit decrease in evapotranspiration. As a result of the regression analysis, the obtained values were found to have changed between 0.68 and 1.87 in the first season and between 0.80 and 2.70 in the second season (Figure 4). A general decrease was experienced in the yield of ungrafted and grafted eggplants in response to the proportional decrease in plant water consumption. However, it could be said that the best results were obtained from the grafted eggplant and the FPRD irrigation.

Canturk et al. (2023) reported that a decrease in evapotranspiration caused a decrease in efficiency. Similarly, Campi et al. (2019) found that deficit irrigation strategies led to a significant reduction in asparagus yield, which was attributed to the development of smaller canopies under water stress conditions. In another study, Abd El-Wahed & Ali (2013) reported that deficit irrigation reduced bean yield to a certain rate. Therefore, previous studies are consistent with the research results of this study.

An important reason why grafted plants perform better than ungrafted plants has been attributed to the deeper and well-developed root system, which can increase the volume of soil that the root system of grafted plants can reach (Ibrahim et al. 2014; López-Marín et al. 2017). Similarly, Consentino et al. (2022) reported that grafted eggplant provided a yield advantage, and this finding is also consistent with that of this study. In line with the results of this research, Sabatino et al. (2018) found that grafted plants consistently produced more fruits per plant than ungrafted ones, and similar findings were found by Sabatino et al. (2016) and Maršič et al. (2014).

4.4. Yield components, biomass and plant height

The results of ANOVA analysis regarding some yield-related parameters showed significant changes at the $P<0.01$ and/or $P<0.05$ level (Tables 5 and 6). It revealed that yield parameters, biomass and plant height were primarily affected by irrigation levels (100%, 80%, 60%, and 40%). A similar result was also observed in the yield, mass, WUE and IWUE values (Tables 3 and 4, Figures 2 and 3). The results of this study were found to be consistent with those of Darko et al. (2019) and Consentino et al. (2022). All parameters were negatively affected by water stress in general. Similar to the results of this research, Ouma et al. (2024) have also reported that deficit irrigation increases eggplant yield. However, the water deficit level mustn't be below 40% for mean fruit weight (g fruit^{-1}).

Gisbert et al. (2011) found that the use of interspecies hybrid rootstock obtained from a fully compatible breed of eggplant with related species could be a valuable approach to improve eggplant production. According to Sabatino et al. (2018) reported that the demand for eggplant grafted seedlings is increasing rapidly, but the yield, obvious quality characteristics and chemical composition of fruits obtained from grafted plants should remain equal or improved compared to ungrafted plants. In addition, Gisbert et al. (2011), Moncada et al. (2013), Maršič et al. (2014) and Sabatino et al. (2016) found that grafting could affect the yield and fruit quality in eggplant. These explanations related to grafting were found to be consistent with the total fruit yield, fruit length, and plant height per plant in Table 6. It is relatively similar to other yield parameters.

Biomass (total leaf+stem) dry weight of the above-ground part of the plant) was generally found to be higher in cultivations where there is no water restriction, and lower in areas where there is water restriction (Tables 5 and 6). Although grafting had no effect, the irrigation×grafting (I×G) correlation with irrigation levels was found to be effective for biomass (Tables 5 and 6). Similar results regarding the biomass were also found in the study conducted by Bozkurt Çolak et al. (2017). In this study, the amount of dry matter was found to increase as the amount of irrigation water applied increased.

In both seasons, the plant size showed a gradual increase in all deficit irrigation levels of ungrafted and grafted eggplant (Figure 5). The plant height was measured as the highest in the grafted eggplant (Tables 5 and 6, and Figure 5) and this is consistent with the findings of Consentino et al. (2022) and Ouma et al. (2024). Grafting had a positive effect on plant height (Tables 5 and 6) and the results are consistent with the results of Miceli et al. (2014).

4.5. SSC, pH and fruit outer color

In the statistical analysis of irrigation levels in both seasons of the study (100%, 80%, 60%, and 40%), grafting and irrigation×grafting (I×G) correlation in the second season, the only change between the pH values was found to be very significant ($P<0.01$) (Tables 7 and 8). The pH, which measures total acidity or alkalinity, is an important factor in the production of vegetables and fruits as it is related to the fruit quality (Darko et al. 2019). The change between the pH values in the research was found to be similar to that of Ouma et al. (2024).

The change between the SSC values was found to be statistically insignificant and similar results were reported by Miceli et al. (2014), Sabatino et al. (2018) and Consentino et al. (2022).

Color measurements were made as L*, a*, and b* with the Minolta CR400 model color chromometer on eggplant fruits, and the values of C (Chroma) and hº (hue) were calculated using the values of *a and *b (Siomos et al. 2002; Madeira et al. 2003). However, it was seen that grafting in the second season affected only fruit color a* ($P<0.05$) (Table 8). In other cases, it was found that the color parameters were not significantly affected, and this result is consistent with that of Sabatino et al. (2018).

5. Conclusions

It was found in the study that the method and level of irrigation water applied had a significant effect on ungrafted and grafted eggplant plants. The amount of irrigation water applied in the study was recorded between 148.45 and 365.48 mm, 245.61 and 584.84 mm in the first and second seasons, respectively. Accordingly, statistically significant changes ($p<0.01$ and/or $p<0.05$ significance level) were found in yield, evapotranspiration, water use efficiency, irrigation water use efficiency values. The regression analysis values between irrigation water and yield were determined at a very good level ($0.80<R^2$). In addition, as an important finding, the regression analysis value of grafting was determined at the highest level (R^2=91) in the second season. In the first season of the study, the highest yields were statistically determined in FPRD100, I100 and FPRD80 (45.26, 44.01 and 39.26 t ha^{-1}, respectively). Similarly, in the second season, the highest yields were obtained from I100 and FPRD100 with 50.97 and 48.96 t ha^{-1}, respectively, followed by FPRD80 with 48.96 t ha^{-1}.

It has been found when compared in terms of irrigation treatments, that grafted eggplant plants in general had a higher total yield than ungrafted plants. However, as the amount of irrigation water applied decreased, yield has also decreased. Although the different irrigation levels applied to grafted and ungrafted eggplant plants were not statistically significant in the first year, the water use efficiency showed similar reactions in the I_{100}, $FPRD_{100}$, $FPRD_{80}$, and $FPRD_{60}$ treatments in the second year. This reveals the advantages of partial-wetting irrigation compared to conventional irrigation. As a result of the research, the cultivation of grafted eggplant plants is recommended and PRD technique should be used in irrigation.

References

Abd El-Wahed M H & Ali E A (2013). Effect of irrigation systems, amounts of irrigation water and mulching on corn yield, water use efficiency and net profit. Agricultural Water Management 120: 64–71

Al-Hadidi L & Sweity A (2022). Effect of deficit irrigation using treated wastewater on eggplant yields, water productivity, fruit quality and mineral contents. Russian Agricultural Sciences 48(2): 63–73. https://doi.org/10.3103/S1068367422020112

Al Ali M, Gençoğlan C & Gençoğlan S (2018). The effect of irrigation water amount on water-yield relationships of eggplant. Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi. 1. Uluslararası Tarımsal Yapılar ve Sulama Kongresi, Special Issue: 385-393

Al-Harbi A R, Al-Omran A M & Alharbi K (2018). Grafting improves cucumber water stress tolerance in Saudi Arabia. *Saudi Journal of Biological Sciences* 25(2): 298–304. https://doi.org/10.1016/j.sjbs.2017.10.025

Anonymous (2000). Long-term climate data for Antalya province. Turkish State Meteorological Service, Antalya.

Anonymous (2022). Ministry of Agriculture and Forestry General Directorate of State Hydraulic Works (DSI). https://cevreselgostergeler.csb.gov.tr/su-kullanimi-i-85738.

Ayas S (2017). The effects of irrigation regimes on the yield and water use of eggplant (Solanum melongena L.). *Soil Water Journal* 6(2): 49-58. https://doi.org/10.21657/topraksu.339835

Bhatnagar V & Poonia R C (2018). Design of prototype model for irrigation based decision support system. *Journal of Informaton and Optmzaton Scences* 39(7): 1607–1612. https://doi.org/ 10.1080/02522667.2018.1507763

Bozkurt Çolak Y, Yazar A & Çolak İ (2017). Effect of different deficit irrigation strategies on subsurface drip irrigated eggplant yields and yield components under Cukurova Condition. Alatarım 16(1): 1-10

Bozkurt Çolak Y, Yazar A, Gönen E & Eroğlu E Ç (2018). Yield and quality response of surface and subsurface drip-irrigated eggplant and comparison of net returns. Agricultural Water Management 206: 165–175. https://doi.org/10.1016/j.agwat.2018.05.010

Bozkurt Çolak Y (2019). Effects of irrigation frequency and level on yield and stomatal resistance of eggplant (Solanum melongena L.) grown in open field irrigated with surface and subsurface drip methods. Applied Ecology and Environmental Research 17(6): 15585–15604. DOI: http://dx.doi.org/10.15666/aeer/1706_1558515604

Cantürk A, Cemek B, Taşan M & Taşan S (2023). Effect of deficit irrigation on yield, water productivity, energy indices and economic productivity in eggplant cultivation. Gesunde Pflanzen 75: 1579-1589. https://doi.org/10.1007/s10343-022-00814-z

Campi P, Mastrorilli M, Stellacci A M, Modugno F & Palumbo A D (2019). Increasing the effective use of water in green aspara gus through deficit irrigation strategies. Agricultural Water Management 217: 119–130

Consentino B B, Rouphael Y, Ntatsi G, De Pasquale C, Iapichino G, D'Anna F, La Bella S & Sabatino L (2022). Agronomic performance and fruit quality in greenhouse grown eggplant are interactively modulated by iodine dosage and grafting. Scientia Horticulturae 295: 110891. https://doi.org/10.1016/j.scienta.2022.110891

Darko R O, Yuan S, Kumi F & Quaye F (2019). Effect of deficit irrigation on yield and quality of eggplant. International Journal of Environment, Agriculture and Biotechnology 4(5): 1325–1333. https://dx.doi.org/10.22161/ijeab.45.5

Diaz-Perez J C & Eaton T E (2015). Eggplant (Solanum melongena L.) plant growth and fruit yield as affected by drip irrigation rate. HortScience 50(11): 1709–1714. https://doi.org/10.21273/HORTSCI.50.11.1709

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

Dry P R & Loveys B R (1998). Factors influencing grapevine vigour and the potential for control with partial rootzone drying. Australian Journal of Grape and Wine Research 4: 140–148. https://doi.org/10.1111/j.1755-0238.1998.tb00143.x

Dry P, Loveys B, Botting D & Düring H (1995). Effects of partial root-zone drying on grapevine vigour, yield, composition of fruit and use of water. In: Proceedings of the ninth Australian Wine Industry Technical Conference pp. 128–131

Ertek A, Şensoy S, Küçükyumuk C & Gedik İ (2006). Determination of plant-pan coefficients for field-grown eggplant (Solanum melongena L.) using class A pan evaporation values. Agricultural Water Management 85(1–2): 58–66. https://doi.org/10.1016/ j.agwat.2006.03.013

FAO (2024). Crops and livestock products. https://www.fao.org/faostat/en/#data/QCL

Gisbert C, Prohens J, Raig´on M D, Stommel J R & Nuez F (2011). Eggplant relatives as sources of variation for developing new rootstocks: effects of grafting on eggplant yield and fruit apparent quality and composition. Scientia Horticulturae 128: 14–22. doi:10.1016/j.scienta.2010.12.007

Howladar S M (2018). Potassium humate improves physio-biochemical attributes, defense systems activities and water-use efficiencies of eggplant under partial root-zone drying. Scientia Horticulturae 240: 179–185. https://doi.org/10.1016/j.scienta.2018.06.020

Ibrahim A, Wahb-Allah M, Abdel-Razzak H & Alsadon A (2014). Growth, yield, quality and water use efficiency of grafted tomato plants grown in greenhouse under dif ferent irrigation levels. *Life Science Journal* 11(2): 118–126. doi:10.7537/marslsj110214.17

Incrocci L, Thompson R B, Fernandez-Fernandez M D, De Pascale S, Pardossi A, Stanghellini C, Rouphael Y & Gallardo M (2020). Irrigation management of European greenhouse vegetable crops. Agricultural Water Management 242: 106393. https://doi.org/10.1016/j.agwat.2020.106393

Kaman H, Özbek Ö & Polat E (2022). Response of greenhouse grown cucumber to partial root zone drying and conventional deficit irrigation. KSU J. Agric Nat. 25(2): 337-347. https://doi.org/10.18016/ ksutarimdoga.vi. 883294

Kaman H, Özbek Ö & Polat E (2023a). Determination of the effect of different irrigation regimes on some quality properties of cucumber. Journal of Tekirdag Agricultural Faculty 20(2): 318-333. DOI: 10.33462/jotaf.1093951

Kaman H, Gübbük H, Tezcan A, Can M & Özbek Ö (2023b). Water-yield relationship of greenhouse-grown strawberry under limited irrigation. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 51(2): 13235. https://doi.org/10.15835/nbha51213235

Kaman H, Gübbük H, Tezcan A, Can M & Özbek Ö (2023c). Yield and quality of strawberry under deficit irrigation and fixed partial root drying regimes. *Pakistan Journal of Agricultural Sciences* 60(4): 555-563. DOI:10.21162/PAKJAS/23.135

Kang S, Hu X, Goodwin I & Jerie P (2002). Soil water distribution, water use, and yield response to partial root zone drying under a shallow groundwater table condition in a pear orchard. Scientia Horticulturae 92(3-4): 277-291. https://doi.org/10.1016/S0304-4238(01)00300-4

Kang S, Liang Z, Pan Y, Shi P & Zhang J (2000). Alternate furrow irrigation for maize production in an arid area. Agricultural Water Management 45(3): 267-274. https://doi.org/10.1016/S0378-3774(00)00072-X

Kang S, Zhang L, Xiaotao H, Li Z & Jerie P (2001). An improved water use efficiency for hot pepper grown under controlled alternate drip irrigation on partial roots. Scientia Horticulturae 89(4): 257–267. https://doi.org/10.1016/S0304-4238(00)00245-4

Karam F, Saliba R, Skaf S, Breidy J, Rouphael Y & Balendonck J (2011). Yield and water use of eggplants (Solanum melongena L.) under full and deficit irrigation regimes. Agricultural Water Management 98(8): 1307-1316. https://doi.org/10.1016/j.agwat.2011.03.012

Khah E M, Katsoulas N, Tchamitchain M & Kittas C (2011). Effect of grafting on eggplant leaf gas exchanges under Mediterranean greenhouse conditions. *International Journal of Plant Production* 5(2): 121–134. https://doi.org/10.22069/ijpp.2012.726

Kirda C, Cetin M, Dasgan Y, Topcu S, Kaman H, Ekici B, Derici M R & Ozguven A I (2004). Yield response of greenhouse grown tomato to partial root drying and conventional deficit irrigation. Agricultural Water Management 69: 191–201. doi:10.1016/j.agwat.2004.04.008

Kirda C, Topcu S, Cetin M, Dasgan H Y, Kaman H, Topaloglu F, Derici M R & Ekici B (2007). Prospects of partial root zone irrigation for increasing irrigation water use efficiency of major crops in the Mediterranean region. Annals of Applied Biology 150: 281-291. doi:10.1111/j.1744-7348.2007.00141.x

Kumar R, Berwal M K & Saroj P L (2019). Morphological, physiological, biochemical and molecular facet of drought stress in horticultural crops. *International Journal of Bio-resource and Stress Management* 10(5): 545-560. DOI: HTTPS://DOI.ORG/10.23910/IJBSM/2019.10.5.2031

López-Marín J, Gálvez A, del Amor F M, Albacete A, Fernández J A, Egea-Gilabert C & Pérez-Alfocea F (2017). Selecting vegetative/generative/dwarfing rootstocks for improving fruit yield and quality in water stressed sweet peppers. Scientia Horticulturae 214: 9–17. https://doi.org/10.1016/j.scienta.2016.11.012

Machado R M A & Serralheiro R P (2017). Soil salinity: effect on vegetable crop growth. management practices to prevent and mitigate soil salinization. Horticulturae 3(2): 30. https://doi.org/10.3390/horticulturae3020030

Madeira A C, Ferreira A, de Varennes A & Vieira M I (2003). SPAD meter versus tristimulus colorimeter to estimate chlorophyll content and leaf color in sweet pepper. Communications in Soil Science and Plant Analysis 34(Nos. 17 &18): 2461-2470. https://doi.org/10.1081/CSS-120024779

Maršič N K, Mikulič-Petkovšek M & Štampar F (2014). Grafting influences phenolic profile and carpometric traits of fruits of greenhouse grown eggplant (Solanum melongena L.). *Journal of Agricultural and Food Chemistry* 62(43): 10504–10514. https://doi.org/10.1021/jf503338m

Meena R P, Karnam V, Sujatha H T, Tripathi S C & Singh G (2024). Practical approaches to enhance water productivity at the farm level in Asia: A review. Irrigation and Drainage 73(2): 770–793. https://doi.org/10.1002/ird.2891

Mekonnen M M & Gerbens-Leenes W (2020). The water footprint of global food production. Water 12: 2696. https://doi.org/10.3390/w12102696

Miceli A, Sabatino L, Moncada A, Vetrano F & D'Anna F (2014). Nursery and field evaluation of eggplant grafted onto unrooted cuttings of Solanum torvum Sw. Scientia Horticulturae 178: 203–210. http://dx.doi.org/10.1016/j.scienta.2014.08.025

Mohawesh O (2016). Utilizing deficit irrigation to enhance growth performance and water-use efficiency of eggplant in arid environments. Journal of Agricultural Science and Technology 18(1): 265–276.

Moncada A, Miceli A, Vetrano F, Mineo V, Planeta D & D'Anna F (2013). Effect of grafting on yield and quality of eggplant (Solanum melongena L.). Scientia Horticulturae 149: 108–114. https://doi.org/10.1016/j.scienta.2012.06.015

Mokabel S, Olama Z, Ali S & El-Dakak R (2022). The role of plant growth promoting rhizosphere microbiome as alternative biofertilizer in boosting solanum melongena l. adaptation to salinity stress. Plants 11(5): 659. https://doi.org/10.3390/plants11050659

Okiror P, Lejju J B, Bahati J, Rugunda G K, Sebuuwufu C I, Mulindwa P & Ocan J J (2017). Suitability of Kabanyolo soils for fruit and vegetable production. *Open Journal of Soil Science* 7(2): 19–33. https://doi.org/10.4236/ojss.2017.72002

Ouma G, Wanyama J, Kabenge I, Jjagwe J, Diana M & Muyonga J (2024). Assessing the effect of deficit drip irrigation regimes on crop performance of eggplant. Scientia Horticulturae 325: 112648. https://doi.org/10.1016/j.scienta.2023.112648

Öktem A, Simsek M & Oktem A G (2003). Deficit irrigation effects on sweet corn (Zea mays saccharata Sturt) with drip irrigation system in a semi-arid region: I. Water-yield relationship. Agricultural Water Management 61(1): 63–74.

Rodan M A, Hassandokht M R, Sadeghzadeh-Ahari D & Mousavi A (2020). Mitigation of drought stress in eggplant by date straw and plastic mulches. *Journal of the Saudi Society of Agricultural Sciences* 19(7): 492–498. https://doi.org/10.1016/j.jssas.2020.09.006

Sabatino L, Iapichino G, Maggio A, D'anna E, Bruno M & D'Anna F (2016). Grafting affects yield and phenolic profile of Solanum melongena L. Landraces. Journal of Integrative Agriculture 15(5): 1017–1024. https://doi.org/10.1016/S2095-3119(15)61323-5

Sabatino L, Iapichino G, D'Anna F, Palazzolo E, Mennella G & Rotino G L (2018). Hybrids and allied species as potential rootstocks for eggplant: Effect of grafting on vigour, yield and overall fruit quality traits. Scientia Horticulturae 228: 81–90. http://dx.doi.org/10.1016/j.scienta.2017.10.020

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

Semida W, Abdelkhalik A, Mohamed G, El-Mageed T, El-Mageed S, Rady M & Ali E (2021). Foliar application of zinc oxide nanoparticles promotes drought stress tolerance in eggplant (Solanum melongena L.). Plants 10(2): 421. https://doi.org/ 10.3390/plants10020421

Sikka A K, Islam A & Rao K V (2018). Climate-smart land and water management for sustainable agriculture. Irrigation and Drainage 67(1): 72-81. https://doi.org/10.1002/ird.2162

Singh G (2016). Climate change and food security in India: Challenges and opportunities. Irrigation and Drainage 65): 5–10. https://doi.org/10.1002/ird.2038

Siomos A S, Papadopoulou P P, Niklis N D & Dogras C C (2002). Quality of Romaine and leaf lettuce at harvest and during storage. ISHS Acta Horticulturae 579: II Balkan Symposium on Vegetables and Potatoes, Acta Horticulturae 579: 641-646. DOI:10.17660/ActaHortic.2002.579.113

Sonawane A V & Shrivastava P K (2022). Partial root zone drying method of irrigation: A review. Irrigation and Drainage 71(3): 574–588. https:// doi.org/10.1002/ird.2686

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

Topcu S, Kirda C, Dasgan Y, Kaman H, Cetin M, Yazici A & Bacon M A (2007). Yield response and N-fertiliser recovery of tomato grown under deficit irrigation. Europ. J. Agronomy 26: 64–70. doi:10.1016/j.eja.2006.08.004

TUIK (2024). Plant Production Statistics. Turkish Statistical Institute, https://data.tuik.gov.tr/Bulten/Index?p=Bitkisel-Uretim-Istatistikleri-2023-49535.

Ungureanu N, Vl˘aduț V & Voicu G (2020). Water scarcity and wastewater reuse in crop irrigation. Sustainability 12: 9055. https://doi.org/10.3390/su12219055

Wakchaure G C, Minhas P S, Meena K K, Kumar S & Rane J (2020). Effect of plant growth regulators and deficit irrigation on canopy traits, yield, water productivity and fruit quality of eggplant (Solanum melongena L.) grown in the water scarce environment. *Journal of Environmental Management* 262: 110320. https://doi.org/10.1016/j.jenvman.2020.110320

Wang B, Bao R, Yan H, Zheng H, Wu J, Zhang C & Wang G (2024). Study of evapotranspiration and crop coefficients for eggplant in a Venlo-type greenhouse in South China. Irrigation and Drainage 1–13. https://doi.org/10.1002/ird.3025

Zafar U, Arshad M, Masud Cheema M J & Ahmad R (2020). Sensor based drip irrigation to enhance crop yield and water productivity in semi-arid climatic region of Pakistan. *Pakistan Journal of Agricultural Sciences* 57(5): 1293–1301. https://doi.org/10.21162/ PAKJAS/20.83

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