ORIGINAL ARTICLE / ORIGINALBEITRAG

Yield, Net Return and Fruit Quality Response of Melon to Deficit Irrigation

Hayrettin Kuscu[1] · **Ahmet Turhan**[2]

Abstract
The efficient use of water in the agricultural sector is an important issue not only for profitable production and high-quality crops but also for the protection of soil and water resources. Field experiments were conducted in Bursa city located in northwest of Turkey with sub-humid climate over clay-loam soils during three consecutive growing seasons (2012–2014). Irrigation treatments included 100% (FI) of crop evapotranspiration (ETc), 75% (DI1), 50% (DI2), and 25% (DI3) of ETc at 3-day intervals via drip irrigation during the growing season. Also, irrigation water was applied as 100% ETc from transplantation to the beginning of flowering (DI4), yield formation (DI5), fruit ripening (DI6), later 50% ETc. Analyses were conducted to determine the effects of different irrigation strategies on fruit yield and quality traits. The amount of irrigation water applied, actual evapotranspiration, net return, and water productivity indicators were calculated separately for each treatment. According to 3-year averages, relatively greater yields (66.47 and 65.18 t ha^{-1}) were obtained from FI and DI6 treatments, respectively. The greatest net return per unit area was received as 4042 € ha^{-1} from FI treatment. The greatest net return per unit volume of irrigation water (1.00 € m^{-3}) and the greatest water productivity (13.73 kg m^{-3}) were obtained from DI6 treatment. Irrigation regimes significantly affected fruit length and diameter, fruit soluble solids content, total sugar, titratable acidity, vitamin C, and protein content. Deficit irrigations improved melon quality traits. Considering the overall yield, quality, water productivity, and net returns, DI6 treatment was recommended for the drip irrigation of melon plants in the sub-humid region of Northwest Turkey.

Keywords Deficit irrigation · Economic analysis · Evapotranspiration · Soluble solids · Water productivity

Hayrettin Kuscu
kuscu@uludag.edu.tr

✉ Ahmet Turhan
turhan@uludag.edu.tr

1   Faculty of Agriculture, Department of Biosystems Engineering, The University of Bursa Uludag, 16059 Gorukle, Bursa, Turkey

2   Mustafakemalpasa Vocational School, Department of Plant and Animal Production, The University of Bursa Uludag, 16500 Bursa, Turkey

Veränderung von Ertrag, Nettoertrag und Fruchtqualität von Melonen bei Defizitbewässerung

Zusammenfassung

Die effiziente Nutzung von Wasser in der Landwirtschaft ist nicht nur ein wichtiges Thema für eine rentable Produktion und qualitativ hochwertige Ernten, sondern auch für den Schutz von Böden und Wasserressourcen. Feldexperimente wurden in der Stadt Bursa im Nordwesten der Türkei mit subhumidem Klima auf Lehmböden in drei aufeinanderfolgenden Vegetationsperioden (2012–2014) durchgeführt. Die Bewässerungsbehandlungen umfassten 100 % (FI) der Evapotranspiration (ETc), 75 % (DI1), 50 % (DI2) und 25 % (DI3) der ETc in 3-Tages-Intervallen mittels Tröpfchenbewässerung während der Vegetationsperiode. Außerdem wurde von der Verpflanzung bis zu dem Beginn der Blüte (DI4), der Ertragsbildung (DI5) und der Fruchtreife (DI6) mit 100 % ETc bewässert, später mit 50 % ETc. Es wurden Analysen durchgeführt, um die Auswirkungen verschiedener Bewässerungsstrategien auf den Fruchtertrag und die Qualitätsmerkmale zu bestimmen. Die Menge des eingesetzten Bewässerungswassers, die tatsächliche Evapotranspiration, der Nettoertrag und die Wasserproduktivitätsindikatoren wurden für jede Behandlung separat berechnet. Nach 3-Jahres-Durchschnittswerten wurden relativ höhere Erträge (66,47 und 65,18 t ha⁻¹) mit FI- bzw. DI6-Behandlungen erzielt. Der größte Nettoertrag pro Flächeneinheit wurde mit 4042 € ha⁻¹ aus der FI-Behandlung erzielt. Der größte Nettoertrag pro Volumeneinheit Bewässerungswasser (1,00 € m⁻³) und die höchste Wasserproduktivität (13,73 kg m⁻³) wurden aus der DI6-Behandlung erzielt. Die Bewässerungsregimes beeinflussten Länge und Durchmesser der Früchte, den Gehalt an löslichen Feststoffen der Früchte, den Gesamtzucker, die titrierbare Säure, den Vitamin-C- und den Proteingehalt signifikant. Defizitbewässerungen verbesserten die Qualitätsmerkmale der Melone. In Anbetracht des Gesamtertrags, der Qualität, der Wasserproduktivität und des Nettoertrags wurde die DI6-Behandlung für die Tröpfchenbewässerung von Melonenpflanzen in der subhumiden Region der Nordwesttürkei empfohlen.

Schlüsselwörter Defizitbewässerung · Wirtschaftliche Analyse · Evapotranspiration · Lösliche Feststoffe · Wasserproduktivität

Introduction

Worldwide about 70–75% of freshwater resources are allocated to irrigated farming (Du et al. 2015). Increasing food demands of ever-increasing populations exert severe pressure on irrigated agriculture, thus generating significant competition in the sectoral allocation of freshwater resources (Sauer et al. 2010). Under current global climate change trends, there is a need for a series of measures to improve crop yields. Such efforts include genetic, environmental, and agronomic practices. Agricultural water management is the primary issue to be considered for sustainable agricultural production and food supply. Precipitations throughout the plant growing seasons are insufficient in several regions. In such areas, water deficiency is the primary factor limiting plant development and yields (Oweis and Hachum 2006; Fan et al. 2014).

Melon is exceptionally rich in vitamins and minerals and has various health benefits. Therefore, it is mostly produced worldwide. In Turkey, vegetables are cultivated over the majority of irrigated lands. Melon production constitutes about 9% of the total vegetable production in Turkey.

On the other hand, the melon yields of Turkey are 12% less than world averages (27.6 t ha⁻¹) (FAO 2020). According to 2016 data, the average melon yield of Turkey is around 24.1 t ha⁻¹, and such a value is entirely below the product of the leader country, China (36.8 t ha⁻¹) (FAO

2020). Therefore, high melon yields may have significant contributions to food safety. Improvement of product per unit of water and land is an important issue; however, soil, water, climate parameters, and farmers' knowledge seriously limit sustainable vegetable production. Farmers generally do not apply scheduled irrigation programs based on soil moisture, reference crop evapotranspiration (ETo), or phenological observations. Such improper irrigations then negatively influence crop yield and quality. Excessive water use reduces water productivity (WP) and increasing input costs reduce net returns.

Irrigation water is the primary limiting factor for crop yields in water-deficit regions. Deficit irrigations may improve WP, provide the right balance among yield, quality, and net return, and offer significant water savings. Water deficit may constitute a significant abiotic stress factor reducing melon yields (Zeng et al. 2009; Wang et al. 2017).

In agricultural areas where irrigation water is scarce and rainfall is insufficient, deficit irrigation applications can be made to increase the efficiency of water use. Deficit irrigation is the application of water below evapotranspiration (ET) and can be achieved in numerous forms. Sustained deficit irrigation (SDI) is the systematic application of water at a constant fraction of potential ET throughout the total crop growth season. Regulated deficit irrigation is implemented by imposing water deficits only at defined crop

growth stages (Fereres et al. 2003; Fereres and Soriano 2007).

Irrigation practices influence plant yield and quality in different fashions. Increasing irrigation frequencies result in cracked fruit skins, and decreasing irrigation frequencies reduce root and shoot development, fruit size, and yield (Pew and Gardner 1983). Earlier studies revealed that water stress in various crop phenological stages effectively increased water productivity (Cabello et al. 2009; Sharma et al. 2014). Deficit irrigations may improve fruit quality, generally reduce yields, but a relative increase in yield may be seen in some cases (Gil et al. 2000; Leskovar et al. 2003; Kirnak and Dogan 2009; Yıldırım et al. 2009). Such a case may vary with the species. Severe and excessive water deficits reduce the number of fruits per plant, fruit size, and yield, but generally increase soluble solids content (Shishido et al. 1992; Bang et al. 2004; Yıldırım et al. 2009). Melon is highly sensitive to water deficits in fruit setting and flowering periods (Fabeiro et al. 2002). Deficit irrigation during the ripening period does not influence fruit yield and relatively increases sugar content (Fabeiro et al. 2002; Yıldırım et al. 2009). Drip irrigation treatments increase fruit size and marketable fruit yields (Leskovar et al. 2001; Dogan et al. 2008; Ozmen et al. 2015). Melon yields may be influenced by applied irrigation quantities in different fashions based on cultivars (Dasgan et al. 1999; Leskovar et al. 2003; Dogan et al. 2008; Yavuz et al. 2021).

Previous studies about the effects of irrigation programs on melon growth and development, yield, and quality revealed that special irrigation programs could be generated for specific cultivars based on natural factors including climate, soil, topography, water resource, and irrigation water requirements could be calculated accordingly. Previous studies mostly focused on the effects of irrigations on melon plant development, yield, and quality but did not focus on the impacts of irrigations on net return in melon farming. Therefore, this study was conducted to investigate the effects of different irrigation strategies on yield, fruit quality, water productivity, and net return of a melon cultivar with a high yield potential grown in clay-loam soils under sub-humid climate conditions. Considering the entire parameters, an optimum irrigation program was tried to be achieved.

Materials and Methods

Soil and Climate Characteristics of Experimental Site

Experiments were conducted in the summer seasons of 2012, 2013, and 2014 over the experimental fields of the Experimental Station of Bursa Uludag University located in the northwest of Turkey. Experimental soils were clay-loam in texture (24% sand, 43% silt, and 33% clay) with a permanent wilting point of $0.24\,m^{-3}\,m^{-3}$, field capacity of $0.39\,m^{-3}\,m^{-3}$, and dry bulk density of $1.41\,g\,cm^{-3}$ for 0–90 cm soil profile. The total available water holding capacity of the site is 189 mm.

Fig. 1 Rainfall during the growing period of melon
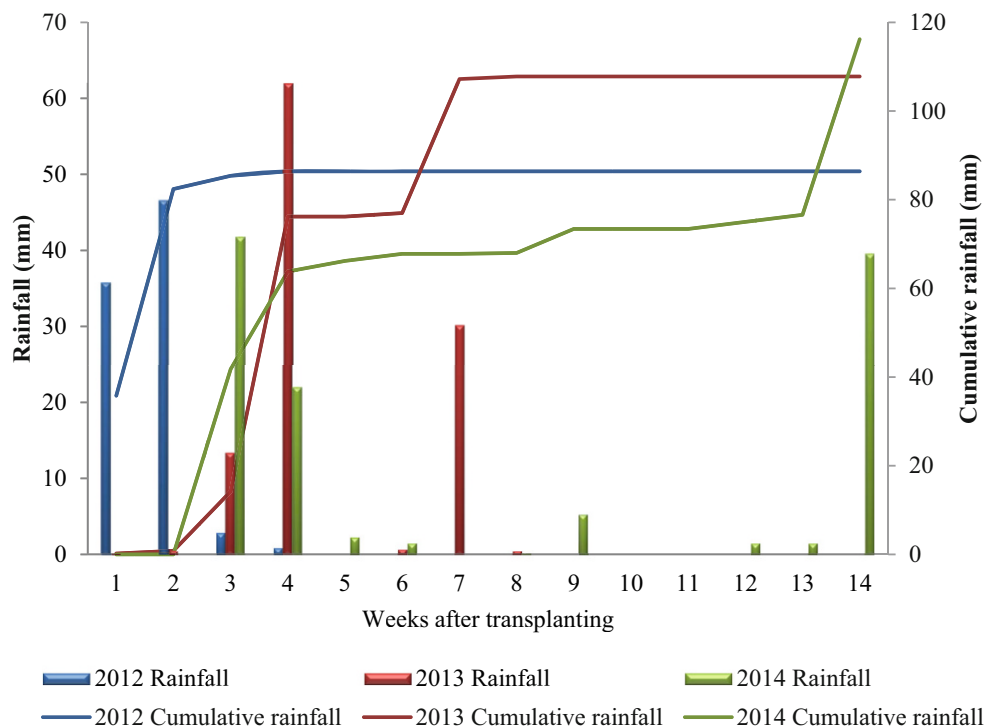
The climate of the experimental site is sub-humid with an annual average precipitation of 681 mm (Iyigun et al. 2013). Annual average temperature and relative humidity are 14 °C and 68%, respectively. Long-term (1975–2011) average precipitation during the growing period of melon (May–August) is 106.7 mm while growing season precipitation measured in 2012, 2013, and 2014 growing seasons was 86.4, 117.8, and 76.6 mm, respectively. Average air temperature during these months varied between 17.5 and 23.2 °C in 2012, between 18.6 and 26.7 °C in 2013, between 20.7 and 24.9 °C in 2014 growing season, and between 19.0 and 25.7 °C for long-term averages. The relative humidity was about 66% in the May-August period of the experimental years. Fig. 1 shows the rainfalls during the melon growing season. Lack of seasonal rainfall is likely to restrict the marketable yield and quality of the melon. Therefore, irrigation was required for satisfactory economic outcomes of melon grown under these ecological conditions.

Experimental Design, Treatments, and Water Application

Field experiments were conducted using a completely randomized block design with three replications. Irrigation treatments investigated are provided in Table 1.

Crop evapotranspiration (ETc, mm) was calculated according to:

$$ETc = E_0 \times Kc \tag{1}$$

where E_0 is the evaporation of standard Class-A pan and Kc is the crop coefficient as suggested by Doorenbos and Pruitt (1977). The Kc values used during the growing season were those proposed in FAO-56 (Allen et al. 1998) for sweet melons (0.30 for the initial stage, 030–1.05 for the crop development stage, 1.05 for the mid-season stage, and 1.05–0.75 for the late-season stage of crop development). The calculated amount of irrigation water was applied at 3-day intervals, and the water was used to the plots via

Table 1 Irrigation treatments

Treatments Description	
FI	100% ETc restoration during the whole growing season
DI1	75% ETc restoration during the whole growing season
DI2	50% ETc restoration during the whole growing season
DI3	25% ETc restoration during the whole growing season
DI4	100% ETc up to the beginning of flowering, then 50% ETc restoration
DI5	100% ETc up to the beginning of yield formation, then 50% ETc restoration
DI6	100% ETc up to the beginning of ripening stage, then 50% ETc restoration

a drip irrigation system. The laterals were installed in each row (1.2 m apart) at a distance of 0.2 m from the plant row. The dripper lines had inline compensating emitter pressure, and the discharge rate of the emitters was 3.0 L h⁻¹ at an operating pressure of 1 bar. The emitter spacing was chosen as 0.40 m based on the soil characteristics. The water pumped from the Mustafakemalpasa Aquifer was filtered through a 150-mesh screen. Water flowed through a manifold instrumented with flow meters, manual valves, pressure regulators, and air vents on each supply line. The system was established in the plots before the seedlings were transplanted into the experimental plots. The first irrigation was practiced immediately after planting and continued until the field capacity to improve crop establishment (40.2 mm in 2012, 16.4 mm in 2013, and 20.5 mm in 2014).

Agronomic Practices

Kırkağaç-Truva hybrid melon cultivar (Fito Seeds™ Inc., Antalya, Turkey) was used as the plant material. Melon seedlings were transplanted at the 3–5 real leaf stages on 17 May 2012, 20 May 2013, and 15 May 2014. Each experimental plot was 7.0 m long and 4.8 m wide (33.6 m²), with four rows per plot. The buffer zone spacing provided between the plots was 3.00 m. Row spacing was 1.2 m, and on-row plant spacing was 1.0 m. According to soil analysis, a total of 120 kg N ha⁻¹, 45 kg P_2O_5 ha⁻¹, and 10 kg K_2O ha⁻¹ were applied in the form of urea, triple superphosphate, and K_2SO_4, respectively. Manual harvests were practiced on 15–22 August 2012, 19–25 August 2013, and 15–22 August 2014.

Measurements

Soil moisture content was monitored within 0–120 cm soil profile in 0.3 m depth increments. Soil samples were taken directly under the drippers. Soil moisture was determined using the gravimetric method (oven-dry basis).

The actual crop evapotranspiration (ETa) under different irrigation regimes was estimated using the following soil water balance equation (Wang et al. 2017):

$$ETa = I + P \pm \Delta S - D \tag{2}$$

where I is the amount of irrigation water (mm), P is the precipitation (mm), ΔS is the change in soil water storage (mm) and D is the deep percolation below the root zone. In the equation, I was measured using water meters, P was observed at the automated weather observing station located 1 km east of the experimental area and ΔS was obtained from gravimetric moisture observations within 0–90 cm soil profile. Whenever the available water in the root zone (0–0.9 m) and the total amount of water ap-

plied by irrigation or rainfall were above the field capacity, the water was assumed to enter the deep percolation below the root zone.

The ripe fruits in each treatment were harvested by hand on 15–28 August 2012, 18–29 August 2013, and 14–26 August 2014. Marketable yield (t ha⁻¹) was measured considering fruits free of disorders (Turhan et al. 2012). Ripened fruits (5 fruits per plot) were sampled for laboratory analyses at harvest. The melons were sliced with rinds, and seeds were removed; afterward, the fleshy mesocarps, the edible portion of the fruit, were analyzed for soluble solids content (SSC), pH, total sugar, vitamin C, titratable acidity, and protein. Soluble solids (°Brix) were measured with an abbe-type refractometer (Model 60, Direct Reading, Bellingham & Stanley Inc., Kent, UK) at 20 °C (Yetışır et al. 2003); pH was measured with a pH meter; vitamin C (mg 100 g⁻¹ as fruit weight (FW)), as ascorbic acid) was determined by titration of homogenate melon samples (AOAC 1998); total sugar (% FW) was determined by the Luff-Schoorl method (Gormley and Maher 1990). Titratable acidity (%) was calculated as the percentage of citric acid in juice (Zhou et al. 2016). Protein content (g 100 g⁻¹) was determined, as defined by AOAC (1998).

Economic Analysis

Net income per unit area (€ ha⁻¹) was calculated by subtracting total production costs from gross income. The gross income was determined by multiplying the 3-year average fruit yields with the local market price of melon (€0.10 kg⁻¹) for each irrigation treatment. Total production costs were determined by summing fixed and variable costs. The fixed costs, including labor (installation, planting, weeding, cultivation, fertilizer application, spraying, and harvesting), land preparation, seedlings, fertilizers, chemicals (insecticides and pesticides), and the drip irrigation system, were considered equal for all experimental treatments. In calculating fixed costs, principles of economic analysis of melon grown in the open field by Yilmaz et al. (2011) were taken into consideration. Surveys and personal interviews were conducted with the farmers to obtain information that would specify the crop management procedures. Finally, the average fixed cost for melon was determined as €2257 per ha. Water and irrigation costs were considered variable costs. The cost of water used (€ ha⁻¹) was calculated by multiplying the water price (€0.02 m⁻³) and the amount of irrigation water per unit area (m³ ha⁻¹). In the study area, since the irrigation water is distributed through the open-canal system, an energy cost was calculated considering using an electric-powered pump (15 kW) to pump water in the drip irrigation system. Electric energy cost (€ ha⁻¹) was calculated by multiplying the irrigation duration (hours ha⁻¹), agricultural electricity

energy cost (€ kW⁻¹), and 15 kW values for each irrigation treatment considering the characteristics of the drip irrigation system used in this study. Thus, the cost of the water used, and the energy cost were summed, and, eventually, variable costs were obtained. The net income per unit of irrigation water (€ m⁻³) was also found by dividing the net income (€ ha⁻¹) by the amount of irrigation water per unit area (m³ ha⁻¹).

Water Productivity

Water productivity (*WP*, kg m⁻³) and irrigation water productivity (*IWP*, kg m⁻³) were calculated by the following equations (Pereira et al. 2012; Wang et al. 2017):

$$WP = \frac{Y}{ETa} \tag{3}$$

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

In Eqs. 3 and 4, *Y* is marketable fruit yield (kg ha⁻¹), *ETa* is volume of seasonal evapotranspiration (m³ ha⁻¹) as measured by water balance, and *I* is volume of seasonal irrigation water applied (m³ ha⁻¹).

In this study, water productivity was also observed from an economic perspective, and economical water productivity (*EWP*, € m⁻³) and economical irrigation water productivity (*EIWP*, € m⁻³) were calculated with the following equations (Pereira et al. 2012; Fan et al. 2018):

$$EWP = \frac{EY}{ETa} \tag{5}$$

$$EIWP = \frac{EY}{I} \tag{6}$$

where *EY* is the monetary value of the achieved marketable yield (€ ha⁻¹) and other abbreviations are defined above.

Yield Response Factor

The yield response factor for the total growing period was determined by the following approach (Stewart et al. 1977; Doorenbos and Kassam 1979):

$$[1 - Ya\,Ym^{-1}] = ky[1 - SETa\,SETm^{-1}] \tag{7}$$

where *Ya* and *Ym* are actual and maximum crop yields, corresponding to *SETa* and *SETm*, seasonal actual and maximum evapotranspiration, respectively, and *ky* is the crop yield response factor.

Table 2 Results of the seasonal irrigation water applied, rainfall, soil moisture differences, and actual crop evapotranspiration

Growing season	Irrigation strategy	Irrigation water applied (mm) [a]	Effective rainfall (mm)	Soil moisture differences (mm)	Actual crop evapotranspiration (mm)
2012 (May 17–August 28)	FI	484	86	−21	549
	DI1	373		−11	448
	DI2	262		+20	368
	DI3	151		+50	287
	DI4	303		+19	408
	DI5	337		+4	427
	DI6	399		−10	475
2013 (May 20–August 29)	FI	432	108	−19	521
	DI1	328		−1	435
	DI2	224		+30	362
	DI3	120		+60	288
	DI4	264		+29	401
	DI5	289		+14	411
	DI6	352		+1	461
2014 (May 16–August 26)	FI	442	116	−31	527
	DI1	336		−13	439
	DI2	231		+17	364
	DI3	126		+47	289
	DI4	276		+16	408
	DI5	307		+2	425
	DI6	369		−54	431

Note: Full irrigation (100% ETc), *DI1, DI2, and DI3* Deficit irrigation of 75% ETc, 50% ETc, and 25% ETc, respectively, *DI4* 100% ETc up to flowering, then 50% ETc, *DI5* 100% ETc up to yield formation, then 50% ETc, *DI6* 100% ETc up to ripening stage, then 50% ETc

[a] Irrigation water applied includes the first irrigation water. The first irrigation event occurred immediately after planting and continued until field capacity to improve crop establishment was reached (40.2 mm in 2012, 16.4 mm in 2013, and 20.5 mm in 2014)

Table 3 Results of variance analysis of yield, fruit length and diameter, soluble solids, pH, titratable acidity, vitamin C, total sugar, and protein content of melon under different irrigation regimes in 2012, 2013, 2014, and combined years

Source	Significance of F-ratios											
	Yield				**Fruit length**				**Fruit diameter**			
	2012	*2013*	*2014*	*3-year*	*2012*	*2013*	*2014*	*3-year*	*2012*	*2013*	*2014*	*3-year*
Year (Y)				**				ns				ns
Treatment (T)	**	**	**	**	**	**	**	**	**	**	**	**
Y × T				**				ns				ns
	Soluble solids content				**pH**				**Titratable acidity**			
	2012	*2013*	*2014*	*3-year*	*2012*	*2013*	*2014*	*3-year*	*2012*	*2013*	*2014*	*3-year*
Year (Y)				**				ns				ns
Treatment (T)	**	**	**	**	ns	ns	ns	ns	ns	*	*	*
Y × T				*				ns				ns
	Vitamin C				**Total sugar**				**Protein**			
	2012	*2013*	*2014*	*3-year*	*2012*	*2013*	*2014*	*3-year*	*2012*	*2013*	*2014*	*3-year*
Year (Y)				**				**				ns
Treatment (T)	**	**	**	**	**	**	**	**	**	**	**	**
Y × T				**				**				ns

ns Non-significant

*, ** Significant at the 5% and 1% level, respectively

Data Analysis

The data were subjected to analysis of variance (ANOVA) for marketable yield and several fruit characteristics using SPSS software (IBM® SPSS® Statistics, version 22.0, Copyright 1989, 2016 SPSS Inc). The significance of the irrigation treatments was determined with the use of the F test. Duncan's multiple range test ($P < 0.05$) was used to compare the group means of irrigation treatments when the F-test was significant. Regression analysis was performed for the relationships between the marketable yield and crop evapotranspiration.

Results and Discussion

Applied Irrigation Water and Actual Crop Evapotranspiration

The amount of irrigation water applied, and seasonal actual crop evapotranspiration (*SETa*) calculated for each irrigation treatment is presented in Table 2. Used irrigation water quantities varied between 120–484 mm. Total precipitations were lower in 2012 than in 2013 and 2014. Therefore, a more significant amount of irrigation water was applied in 2012. As an average of 3 years, the greatest quantity of irrigation water was applied in FI treatments. *SETa* of melon varied with the treatments and the years. *SETa* values ranged from 287 to 549 mm across the growing seasons. The greatest *SETa* was observed in FI treatments and the least in DI3 treatments with severe soil water stress. *SETa* decreased with decreasing irrigation water quantities. Crop evapotranspiration values generally vary based on climate and soil conditions. In line with the results obtained from this study, Sensoy et al. (2007) reported seasonal evapotranspiration values as between 406–636 mm and Yıldırım et al. (2009) as between 292–605 mm. However, lower crop evapotranspiration values were also reported. In a similar study carried out in a semi-arid region in Turkey by Yavuz et al. (2021) on the effect of water stress applied at various phenological stages on melon, crop evapotranspiration of 429 mm was obtained for full irrigation treatment.

Analysis of Variance for Fruit Yield and Quality Parameters

According to the analysis of variance, yield, soluble solids content, vitamin C, and total sugar parameters were significantly different over three years ($p < 0.01$). Year × irrigation interactions were also significant for yield, vitamin C and total sugar ($P < 0.01$), and soluble solids content ($P < 0.05$) (Table 3). According to an average of 3 years, the effects of irrigation treatments on all parameters, except for pH, were significant. Differences between the years in terms of yield, fruit length, fruit diameter, soluble solids content, vitamin C, total sugar, and protein were also found to be significant ($p < 0.01$). In 2013 and 2014, irrigation treatments also significantly affected titratable acidity ($p < 0.05$).

Fruit Yield

Data obtained from the 3-year study showed that fruit yield was significantly ($P < 0.01$) affected by soil water deficits (Table 4). The average yield was more significant in 2012 (52.92 ton ha⁻¹) than in the other years. In 2012, the greatest yield was obtained from FI treatment without water stress, and DI6, DI1 respectively followed it, and DI5 treatments, and the lowest yield was obtained from DI3 treatment with severe water stress. In 2013 and 2014, irrigation regimes had similar effects, and the greatest yield was obtained from FI and DI6 treatments and the lowest from DI3 treatment. However, yields of deficit irrigation treatments were closely dependent on rainfall and its distribution during the crop cycle. As is evident, deficit irrigated (DI2–DI5) melons had severe yield reductions. The yield of any treatment (DI4–DI5) exposed to water stress at one growth stage was significantly lower than the fully irrigated (FI) control treatment during all experimental years.

While fruit yields in FI treatments of 2012, 2013, and 2014 were respectively recorded as 67.51, 66.15, and 65.75 t ha⁻¹, the yields in 50% water deficits in flowering (DI4) or yield formation (DI5) periods were respectively observed as 49.66, 47.16 and 51.58 and respectively as 56.66, 54.87 and 55.60 t ha⁻¹. Relatively high yields (65.44, 64.82, and 65.28 t ha⁻¹) were observed in DI6 treatments with deficit irrigations in the ripening stage. Such a case indicated a relatively high tolerance of melon to water

Table 4 Melon fruit yields (t ha⁻¹)

Treatment	2012	2013	2014	3-year
FI	67.51a	66.15a	65.75a	66.47a
DI1	57.83c	58.12b	56.00b	57.32c
DI2	47.83e	45.16e	47.33d	46.77f
DI3	25.50f	27.12f	24.85e	25.82g
DI4	49.66d	47.16d	51.58c	49.47e
DI5	56.66c	54.87c	55.60b	55.71d
DI6	65.44b	64.82a	65.28a	65.18b
Mean	52.92A	51.91B	52.34B	52.39
CV (%)	25.34	24.77	25.16	24.72

Note: Full irrigation (100% ETc); *DI1, DI2, and DI3* Deficit irrigation of 75% ETc, 50% ETc, and 25% ETc, respectively, *DI4* 100% ETc up to flowering, then 50% ETc, *DI5* 100% ETc up to yield formation, then 50% ETc, *DI6* 100% ETc up to ripening stage, then 50% ETc Within each column, values followed by the small same letter are not significantly different at $P < 0.05$. Uppercase letters show the differences among the years in the same line

Table 5 Net income

Treatment	Fixed crop production cost (€ ha⁻¹)	Water cost (€ ha⁻¹)	Water pump cost via electrical pump (€ ha⁻¹)	Total cost for irrigation labor (€ ha⁻¹)	Total cost for 1 year (€ ha⁻¹)	Gross income to land (€ ha⁻¹)	Net income to land (€ ha⁻¹)	Net income to irrigation water (€ m⁻³)
FI	2257	97	116	135	2605	6647	4042	0.84
DI1	2257	75	89	104	2525	5732	3207	0.86
DI2	2257	52	63	73	2445	4676	2231	0.85
DI3	2257	30	37	42	2366	2582	216	0.14
DI4	2257	61	73	84	2475	4947	2472	0.82
DI5	2257	67	81	94	2499	5571	3072	0.91
DI6	2257	80	96	112	2545	6519	3974	1.00

Note: Full irrigation (100% ETc); *DI1, DI2, and DI3* Deficit irrigation of 75% ETc, 50% ETc, and 25% ETc, respectively, *DI4* 100% ETc up to flowering, then 50% ETc, *DI5* 100% ETc up to yield formation, then 50% ETc, *DI6* 100% ETc up to ripening stage, then 50% ETc

Table 6 Water productivity

Treatment	WP (kg m⁻³)	IWP (kg m⁻³)	EWP (€ m⁻³)	EIWP (€ m⁻³)
FI	12.10	13.74	0.74	0.84
DI1	12.78	15.38	0.72	0.86
DI2	12.73	17.86	0.61	0.85
DI3	9.01	17.09	0.08	0.14
DI4	12.12	16.35	0.61	0.82
DI5	13.04	16.55	0.72	0.91
DI6	13.73	16.33	0.84	1.00

Note: Values are the mean of nine replication of each treatment over three years. Full irrigation (100% ETc), *DI1, DI2, and DI3* Deficit irrigation of 75% ETc, 50% ETc, and 25% ETc, respectively, *DI4* 100% ETc up to flowering, then 50% ETc, *DI5* 100% ETc up to yield formation, then 50% ETc, *DI6* 100% ETc up to ripening stage, then 50% ETc

shortage in the soil profile during this stage. Significant yield reductions were observed when 50% of water deficits were applied in the flowering period and so on. Comparing the deficit irrigation treatments (DI1–DI3) during the whole growth stages showed that a high deficit irrigation strategy (DI3) produced heavy yield losses. When the deficit irrigation treatments were assessed, the greatest fruit yield was obtained from DI1 treatment with a 25% water deficit during whole growth stages. These findings revealed that melon plants are sensitive to water deficits, massive water deficits resulted in severe yield reductions, and water deficits in the ripening stage resulted in less yield reduction than water deficits applied in the other growth stages. Complying with the present findings, Cabello et al. (2009) indicated that moderate water stress (irrigation of 75% ETc) did not cause severe yield reductions but increasing water stress (irrigation of 60% ETc) resulted in significant yield reductions. Fabeiro et al. (2002) and Li et al. (2012) reported that deficit irrigation in the fruit swelling period reduced muskmelon yields. Yavuz et al. (2021) reported that full irrigation treatment produced the highest yield (52.9 t ha⁻¹) and water stress during the flow-

ering period significantly reduces the yield. In line with the findings obtained in this study, they also stated that soil water restriction during flowering and maturation periods significantly reduces fruit yield. Yavuz (2021) reported that the highest fruit yield (71.2 t ha⁻¹) was achieved from non-stressed treatment, and water stress decreased the yield. On the other hand, some researchers have reported the highest fruit yield under moderate water stress (da Silva et al. 2007; Al-Mefleh et al. 2012). Present findings revealed that fruit volume, weight, and yield varied with irrigation timing and level of water stress, and heavy stress conditions resulted in significant yield losses.

Net Income

Farmers generally target to maximize yields and net returns with the optimum input use rather than water saving. Economic analysis was conducted in this study, and the results are provided in Table 5. Increasing unit water cost, the energy cost for pumping water into the system, and irrigation labor cost increased with increasing irrigation water quantities and irrigation durations. The greatest net return per unit area was obtained from FI (100% ETc) treatment. The greatest net return per unit volume of irrigation water was received from DI6 treatment (100% ETc from the seedling plantation to ripening and 50% ETc in the ripening period). In this case, two recommendations could be stated to growers. If there is no problem with water resources and the irrigation-related costs are not high, then net return per unit area should be considered and 100% ETc should be applied throughout the entire growing season. However, if there is a water deficit and irrigation-related costs are high, then DI5 and DI6 treatments (100% ETc from planting to fruit formation and/or ripening stages and 50% ETc later on) could be recommended. Based on present findings, 25% ETc was not recommended in any case since this treatment had relatively low net return per unit area and unit volume

of irrigation water, thus was not able to offer a profitable growth.

Water-yield-net Return Relationships

Water productivity values under different irrigation regimes are given in Table 6. The greatest WP value was obtained from DI6 treatment and the lowest from DI3 treatment. Such findings revealed that water deficits only in the ripening stage offered more efficient water use and greater yield levels, but heavy water stress throughout the entire growing season (75% water deficit) was not a good strategy for efficient water use. On the other hand, the greatest IWP value was obtained from DI2 treatment and the lowest from FI treatment. Complying with the present findings, Zeng et al. (2009) also reported decreasing IWP values with increasing irrigation water quantities. In this research, the water productivity of different irrigation strategies was also assessed over the net returns. Accordingly, the greatest net return per unit of crop water consumption was obtained from DI6 treatment (EWP = €0.84 m^{-3}), and FI, DI1, and DI5 treatments respectively followed it.

Similarly, the greatest net return per unit of applied irrigation water was obtained from DI6 treatment (EIWP = €1.00 m^{-3}). Except for IWP, the greatest values of all indicators were obtained from DI3 treatment. Considering the entire water productivity indicators together, it was observed that DI6 treatment could be regarded as an essential deficit irrigation strategy.

There were significant relationships between irrigation water and yield (2nd-degree polynomial, $R^2 = 0.955$) (Fig. 2). Accordingly, maximum yield was achieved with around 470 mm total irrigation water quantity, and an increase in yield beyond this level of irrigation water gradually decreased. Although the greatest yield was obtained from FI treatment in which 100% of ETc was applied, optimum yield could be attained with the application of between 70–100% of ETc. Similarly, Yıldırım et al. (2009) indicated
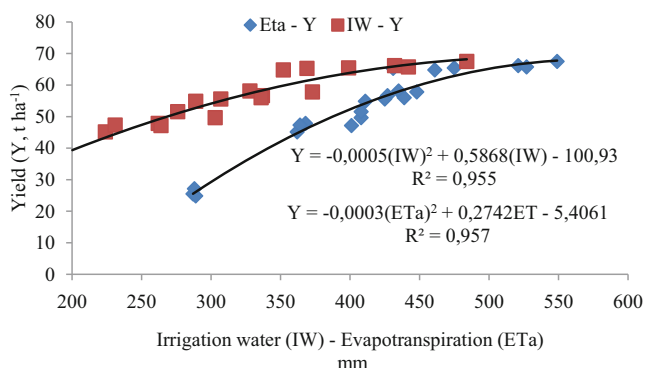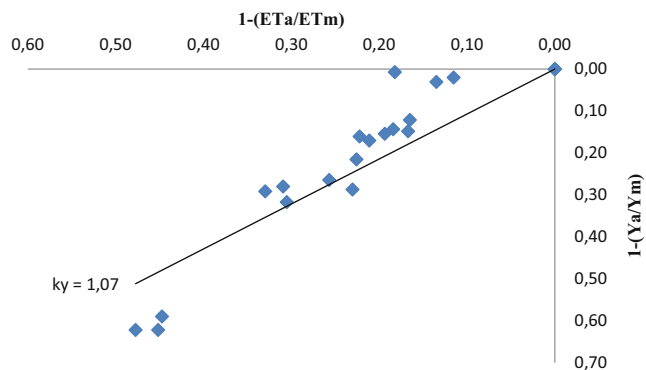

Fig. 3 Relationship between relative yield decrease [1-(Ya/Ym)] and relative crop evapotranspiration decrease for melon throughout the total growing season (three-year average combined data)

that for high yield in melon, irrigations should be sustained until the beginning of ripening and should not be performed in the ripening stage. Besides, 75% of full irrigation was the best irrigation strategy in melon farming. Kırnak et al. (2005) reported greater biomass, fruit yield, single fruit weight, and leaf relative water content for full irrigation (100% of Class-A pan evaporation) and 120 kg N ha^{-1} treatments than for deficit irrigation and greater N treatments. Zeng et al. (2009) reported a linear relationship between irrigation water quantity and muskmelon yield. The Linear or polynomial nature of such relationships between yield and irrigation water quantity broadly varies based on climate, soil, and plant characteristics.

In general, yields increased up to certain level with increasing crop water consumptions and a 2nd degree polynomial relationship ($Y = -0.0003(ETa)^2 + 0.2742ET - 5.4061$;
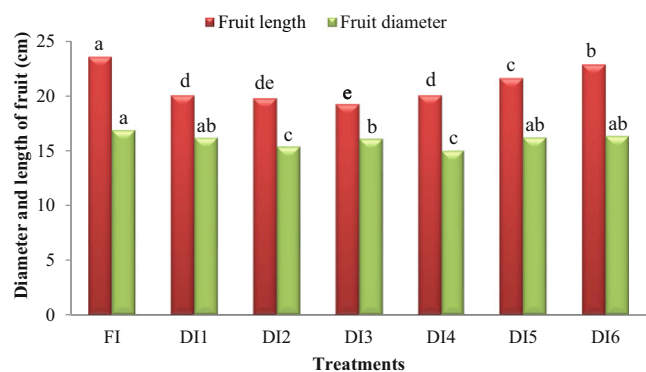

Fig. 2 Irrigation water-yield and actual evapotranspiration-yield relationships

Fig. 4 Mean values for combined years (2012, 2013, and 2014) of diameter and length of melon fruits. Mean values within the treatments by different letters (**a–e**) are significantly different at the probability level of 5%. Values are the mean of nine replication of each treatment over three years. Note: Full irrigation (100% ETc); DI1, DI2, and DI3: Deficit irrigation of 75% ETc, 50% ETc, and 25% ETc, respectively; DI4: 100% ETc up to flowering, then 50% ETc; DI5: 100% ETc up to yield formation, then 50% ETc; DI6: 100% ETc up to ripening stage, then 50% ETc

$R^2 = 0.957$) was observed between these parameters (Fig. 2). The mathematical function had a highly significant determination coefficient.

The yield response factor is used as an indicator of plant tolerance to water stress. The Ky values of greater than 1 indicate that relative reduction in yield for a particular reduction in evapotranspiration was greater than the relative reduction in ET. The yield response factor was calculated as 1.07 for the total crop growing season (Fig. 3).

Fruit Physical and Chemical Properties

While treatments had a significant effect on fruit diameter and length, effects of years were not found to be significant (Fig. 4). The most elongate fruits were obtained from FI treatment, and DI6 and DI5 treatments respectively followed it. The lowest fruit lengths were obtained from DI2 and DI3 treatments. The effects of irrigation treatments on

Table 7 Some quality properties of melon for different irrigation treatments in 2012, 2013, and 2014

Year	Treatment	Soluble solids content (ºBrix)	Vitamin C (mg/100 g)	Total sugar (%)
2012	FI	6.03e	12.50f	7.70b
	DI1	9.03c	16.30d	9.23a
	DI2	11.97 b	19.57c	7.90b
	DI3	13.57a	13.73e	7.33b
	DI4	11.47b	21.25b	7.83b
	DI5	9.50c	22.57a	9.27a
	DI6	7.53d	14.32e	7.80b
	Mean	9.87 B	17.18B	8.15 B
2013	FI	7.10f	14.92e	7.87c
	DI1	9.20d	18.62c	9.53a
	DI2	12.90a	20.26b	8.73b
	DI3	13.03a	14.82e	7.83c
	DI4	12.27b	23.57a	8.53b
	DI5	10.30c	21.09b	9.64a
	DI6	8.27e	16.18d	8.42b
	Mean	10.44A	18.49A	8.65 A
2014	FI	7.43e	15.58d	7.53e
	DI1	9.80d	19.37c	9.17a
	DI2	12.20b	20.49bc	8.60bc
	DI3	13.73a	13.42e	8.03d
	DI4	11.07c	24.46a	8.27cd
	DI5	9.97d	21.08b	9.00ab
	DI6	7.87e	16.45d	8.80ab
	Mean	10.30A	18.69A	8.49 A

Note: Full irrigation (100% ETc), *DI1, DI2, and DI3* Deficit irrigation of 75% ETc, 50% ETc, and 25% ETc, respectively, *DI4* 100% ETc up to flowering, then 50% ETc, *DI5* 100% ETc up to yield formation, then 50% ETc, *DI6* 100% ETc up to ripening stage, then 50% ETc. Within each column, values followed by the same small letter are not significantly different at $P < 0.05$. Uppercase letters show the differences among the years in the same column

fruit diameter were relatively lower than the effects on fruit length, and relatively wider fruits were obtained from FI, DI1, DI5, and DI6 treatments.

Soluble solids contents significantly varied with the years and greater values were observed in 2013 and 2014 than in 2012 (Table 7). As an average of 3 years, greater SSC values were observed under moderate and high-water deficit levels (DI2 and DI3), and the lowest SSC values were obtained from FI treatment. Parallel to the present findings, Zeng et al. (2009) reported lower SSC values for full irrigations or high-water stress treatments than for deficit irrigations. Long et al. (2006) stated that a decrease in soil water content before or during harvest could considerably decrease the SSC. Bustan et al. (2005) indicated that irrigation water salinity could influence SSC values.

Vitamin C contents of melon fruits significantly varied with the years. In the first year, the greatest vitamin C content was obtained from DI5 treatment, it was respectively followed by DI4 and DI2 treatments, and the lowest value was obtained from FI treatment. In the second year, the greatest vitamin C content was obtained from DI4 treatment, and it was respectively followed by DI5 and DI2 treatments. In the third year, greater vitamin C contents were obtained from DI4, DI5, and DI2 treatments (Table 7). Present findings revealed that vitamin C contents increased under deficit irrigation conditions, and vitamin C contents varied based on the type of irrigation scheduling and soil moisture stress levels. Differences in vitamin C contents of the years were attributed to the amount and distribution of precipitation throughout the growing season and resultant differences in soil moisture contents and plant nutrient uptakes. Contrary to present findings, Zeng et al. (2009) reported insignificant effects of irrigation water quantities on vitamin C levels. On the other hand, Wang et al. (2017) indicated that melon vitamin C content was quite sensitive to water stress at the fruit swelling stage.

Average total sugar contents were greater in the second and third years than in the first year (Table 7). Despite lower effects of irrigation treatments on total sugar content in the first year, relatively greater values were obtained from DI1 and DI5 treatments. Similar findings were also observed in the second year, and the lowest total sugar contents were obtained from FI and DI3 treatments. In the third year, DI1, DI5, and DI6 treatments had relatively greater total sugar content. Zeng et al. (2009) indicated that different irrigation levels influenced melon total sugar contents, slight water deficits resulted in greater total sugar contents, and severe water stress and full irrigations reduced total sugar contents. Fabeiro et al. (2002) reported that deficit irrigation applied during the ripening stage could improve the sugar content of melon.

Irrigation treatments did not have significant effects on pH values. The average pH value was measured as 5.78.

There were significant differences in the pH of the years. However, the effects of irrigation treatments on titratable acidity values were found to be significant (Fig. 5). DI4 and DI2 treatments yielded greater titratable acidity values than the other treatments. The lowest titratable acidity values were observed in FI, DI3, and DI6 treatments.

The protein contents of melon fruits did not vary over the years. The greatest protein content was obtained from DI4 treatment and the lowest from FI treatment (Fig. 5). Contrary to present findings, Zeng et al. (2009) reported decreasing protein content with decreasing irrigation water quantities.

Conclusion

Present findings revealed that different irrigation strategies significantly influenced fruit yield, quality, water productivity, and net returns of melon farming under field conditions. The greatest fruit yield, single fruit weight, and net returns were obtained from FI treatments in which 100% of ETc was supplied throughout the entire growing season. Despite relative decreases in yields, deficit irrigations improved quality parameters. According to an average of 3 years, deficit irrigations increased fruit soluble solids content, vitamin C, titratable acidity, and total sugar values compared to full irrigation treatment. It was concluded that irrigation strategies and soil moisture stress levels resulted in differences in melon quality parameters. It was also concluded that significant yield and net return losses were experienced based on timing and level of water stress. Present findings revealed that considering high profitability in melon farming, 100% ETc (full irrigation) throughout the

entire growing season is recommended for the regions with similar conditions (climate, soil properties, variety, etc.) if there are no restrictions for water supply.

On the other hand, in regions experiencing water deficits and considering the fruit quality, deficit irrigation strategies could be selected. Among the current deficit irrigation strategies, the one with 100% ETc up to the beginning of the ripening stage, then 50% ETc later on (DI6) could be preferred. In this treatment, as compared to full irrigation, only a 1.9% reduction was encountered in yield and 1.7% in net return, but 17.5% saving was achieved from the irrigation water. The greatest net return per unit of irrigation water, water productivity, economical water productivity, and economical irrigation water productivity values were obtained, and significant improvements were achieved in quality parameters with this treatment (DI6).

Conflict of interest H. Kuscu and A. Turhan declare that they have no competing interests.

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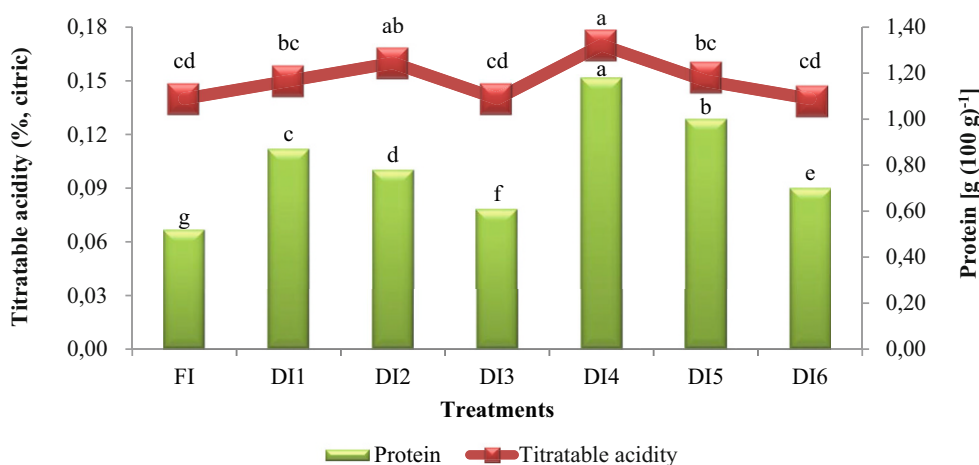
Fig. 5 Mean values for combined years (2012, 2013, and 2014) of titratable acidity and protein content of melon fruits. Mean values within the treatments by different letters (**a–e**) are significantly different at the probability level of 5%. Values are the mean of nine replication of each treatment over three years. Note: Full irrigation (100% ETc); DI1, DI2, and DI3: Deficit irrigation of 75% ETc, 50% ETc, and 25% ETc, respectively; DI4: 100% ETc up to flowering, then 50% ETc; DI5: 100% ETc up to yield formation, then 50% ETc; DI6: 100% ETc up to ripening stage, then 50% ETc

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Ahmet Turhan works as Assoc. Prof. Dr. in the Crop and Animal Production Department, Bursa Uludag University, Turkey. His scientific fields and technical expertise and interests are vegetable growing, plant nutrition, water and salt stress in vegetables, improving plant yield and tolerance to constraints under various stress conditions.