Crop water productivity and yield response of two greenhouse basil (*Ocimum basilicum* L.) cultivars to deficit irrigation

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ABSTRACT

This two-year study aimed to determine the most appropriate irrigation scheduling and crop water productivity (CWP) of basil plant under controlled conditions in Ferdowsi University of Mashhad, Iran. The experimental layout was a split-plot design with three replications. Three deficit irrigation (DI) levels (DI0: 100%, DI30: 70% and DI60: 40% of the field capacity) and two basil cultivars (Green and Purple) were applied to main and subplots, respectively. The results showed that there was a decrease in yield and an increase in CWP for fresh leaves and fresh and dry herb by decreasing the irrigation water. However, a significant difference between fresh leaves and fresh and dry herb yield of DI0 and DI30 treatment was not observed. The Green basil had higher leaves and herb yield and CWP than other cultivar. A polynomial relationship was stablished between fresh leaves yield and crop evapotranspiration, however the yield response factor (Ky) indicated a linear relationship between the relative reduction in crop evapotranspiration vs. the relative reduction in yield. The Ky values were obtained as 0.70 and 0.76 for Green and Purple basil, respectively. The results revealed that the irrigation regime of 30% water saving could insure acceptable yield of basil plant and increase in CWP, especially for the Green basil cultivar.

Key words | evapotranspiration, fresh leaves yield, irrigation, water stress, yield response

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HIGHLIGHTS

- DI was tested for the basil cultivars during a two-year study.
- Basil yields decreased and CWP increased depending on the DI levels.
- DI30 was more effective in saving irrigation water along with a good marketable yield compared to DI0.
- A polynomial relationship was stablished between fresh leaves yield and ET, however crop Ky indicated a linear relationship between the relative ET reduction vs. the relative yield reduction.

INTRODUCTION

Basil (*Ocimum basilicum* L.) belonging to the Laminaceae family is one of the most important medicinal plants, which is widely grown for purposes of food and industry (Hartley *et al.* 2000). Closely 60 species of the basil plant exist across the world and are cultivated in Israel, Hungary, Egypt, the United States, France, Greece, Morocco and Indonesia (Srivasta 1980). The economic organs of the basil plant are seed and leaf (Arabaci & Bayram 2004). Basil with diuretic, stimulant, expectorant and carminative properties has been utilized for stomachache, cough,

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warms, headaches folk medicine (Simon *et al.* 1990; Arabaci & Bayram 2004). It is known as a source of aroma components and therefore has a range of biological attributes like flea and moth repellent, insecticide and anti scorpion, snake and insect bite (Juliani & Simon 2002; Lee *et al.* 2005; Ekren *et al.* 2012). Furthermore, the fresh and dry leaves of the basil plant are much popularly consumed in the spice and food industry (Ekren *et al.* 2012).

The cultivation of medicinal plants has long been common practice to create diversity and sustainability in Iran agricultural systems. Among the species of Laminaceae family, *O. basilicum* is cultivated as the most important economic species in most regions of Iran for fresh consumption and rarely for production of essential oils and as the dry product (Hamzezadeh *et al.* 2011). Water availability is the main challenge for crop production in Iran. The increasing population and rising water and food demand on the one hand, and recent drought and restricted availability of water, on the other hand, have needed the suitable use of available water resources (Albaji 2010; Mahjoobi *et al.* 2010; Hooshmand *et al.* 2019).

Irrigation scheduling and technologies may be improved for more rational and efficient uses of limited water resources (Abdullatif & Asiri 2012). Deficit irrigation (DI) is a proper method to decrease the amount of applied water especially in arid and semi-arid regions with scarcity of water (Safi *et al.* 2019). In DI conditions, the crop faces a particular water stress level either during a special period or the whole growing season (Khalid 2006; Abdullatif & Asiri 2012). However, depending on the locations, DI may have different effects on the same crops (Kresovic *et al.* 2016) and this is a way of improving crop water productivity (CWP) for higher production per unit of evapotranspirated water (Abdullatif & Asiri 2012). Thus, it is significant to detect sensitivity of plants for mitigating the effect of DI.

The basil plant has been investigated in different studies to determine yield component, yield, composition of essential oil, essential oil ratio, plant densities and fertilization in diverse climate and soil conditions. However, few experiments have studied the effect of applied irrigation volume. Ekren *et al.* (2012) and Moeini Alishah *et al.* (2006) reported that water stress reduced yields and plant height of Purple basil, while it had positive effect on the essential oil, proline and anthocyanin content. In contrast, Khalid (2006) indicated that irrigation with 75% of field capacity (FC) on both American basil and sweet basil resulted the highest herb yield and essential oil content compared with other irrigation water levels (50 and 100% of FC). According to Bekhradi *et al.* (2015), many quality characteristics of Genovese variety and Iranian cultivars (Green and Purple) of basil during storage were unchanged by reduced irrigation. Gao (2015) indicated that DI improved water use efficiency, but had different effects on yield of basil plants. Daily irrigation with 75% of crop evapotranspiration had higher yield (18% increase), while irrigation with 75% of crop evapotranspiration every six days had lower yield (12% decrease) compared to the irrigation with 100% of crop evapotranspiration.

Sensitivity of the basil plant to the irrigation and water stress could be characterized by the CWP and yield response factor (Ky) (Pejic *et al.* 2017). Defined as the unit increment in crop yield per unit of water consumed, CWP can be calculated if the amounts of actual crop evapotranspiration and actual yield are known (Igbadun *et al.* 2006). Ky demonstrates the relation between a relative yield reduction (1–Ya/Ym) and a relative evapotranspiration reduction (1–ETa/ETm) (Doorenbos & Kassam 1979). The crop with Ky value lower than one is known as tolerant to water deficit. In turn, when Ky value is greater than one, the crop is considered as not tolerant to DI (Alomran *et al.* 2013).

Efficient use of water resources is needed due to the expected water scarcity in the face of climate change and growing competition of water resources between domestic, industrial and agricultural consumption (Gholami Zali & Ehsanzadeh 2018). Therefore reducing the volume of irrigation water, while maintaining quality and yield are considered desirable in regions where water availability is a main restriction. The aims of the present study were (i) to evaluate the effect of different DI levels on yield and CWP of Green and Purple basil cultivars under greenhouse conditions, and (ii) to determine the sensitivity of two basil cultivars to water stress by Ky.

MATERIALS AND METHODS

Site description

The experiment was carried out under greenhouse condition at the Faculty of Agriculture, Ferdowsi University of

Mashhad, Iran during the spring and summer of 2017 and 2018. The study was located at 36°18′N latitude, 59°38′E longitude and 995 m altitude. The culture of the basil plants was conducted in soil in a unit of the greenhouse with 6 m width, 10 m length and 3 m height. LS16 equipment by AP Holland was applied to monitoring the agrometeorological parameters. The temperature of greenhouse was controlled to maintain at 25–30 °C in both study years. The temporal variations of daily and cumulative radiation during the growing season are presented in Figure 1. The soil in the experimental location was silty clay loam. The main physicochemical properties of the soil in the study area are shown in Table 1.

Experimental design and treatments

The experiment was a split plot layout as randomized complete block design with three replications per irrigation treatment and cultivars as the main plot and the subplot, respectively. Each plot consisted of four rows with 90 cm length and 25 cm distance with each other. A space of 0.5 m was considered between plots to minimize irrigation edge effects. In addition, aluminum plates with 2 mm thickness were used between plots to prevent water leakage to adjacent plots down to depth of 0.5 m.

Basil (*Ocimum basilicum* L.) cultivars were Green and Purple from Mashhad, Razavi Khorasan province, Iran. Irrigation treatments included a control treatment established as 100% of the FC (DI0) and two DI treatments as a percentage of water used for the control treatment (DI30, i.e., a 70% of the FC and DI60, i.e., a 40% of the FC). The irrigation treatments were determined according to the soil water deficit defined as the amount of soil water in the root zone between FC and before irrigation. The soil water content in the top 30 cm was measured using time-domain reflectometry (TDR) probes one day prior to each irrigation at the DI0 treatment plots (3 points in each plot) in order to determine the soil water deficit. The volume of irrigation water applied (V_m, L) to refill this deficit to the FC at the DI0 treatment plots was determined as follows:

$$V_m = \frac{(\theta_F - \theta_i)}{100} \times BD \times D \times A \quad (1)$$

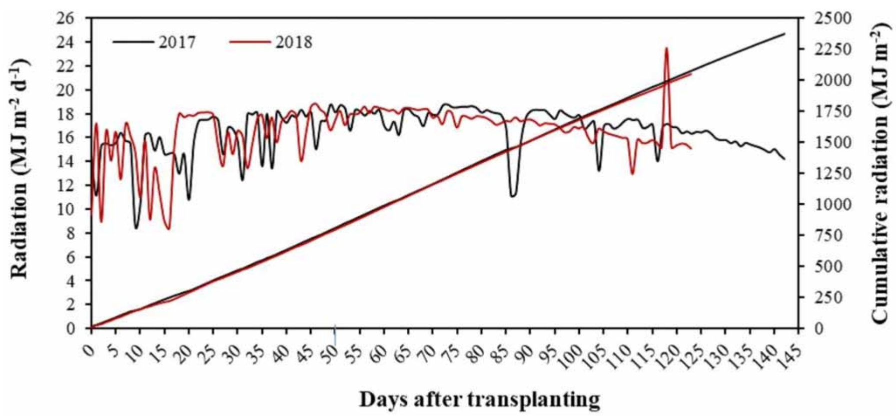

Figure 1 | The temporal variation of daily and cumulative radiation during basil growing seasons in 2017 and 2018.

Table 1 | Physical and chemical characteristics of the experimental soil

Year	Texture	θ_F[a] (g g^{-1})	BD[b] (g cm^{-3})	PH	EC (dS m^{-1})	N (%)	P (mg kg^{-1})	K (mg kg^{-1})
2017	Silty clay loam	22.38	1.54	7.25	0.91	0.06	33.0	176.8
2018	Silty clay loam	21.01	1.23	7.79	1.05	0.12	29.5	183.1

[a]θ_F denotes soil water content at the field capacity.
[b]BD is bulk density.

where θ represents the gravimetric soil water content at the field capacity (F) and before irrigation (i) (g g^{-1}), BD denotes the soil bulk density (g cm^{-3}), D is the depth of root development (cm), and A represents the plot area (m^2). A depth of 30 cm was considered as the depth to be irrigated (Ekren *et al.* 2012).

Irrigation amounts at DI0 treatment were represented in Table 2. The volume of irrigation water for DI30 and DI60 treatments was obtained by applying coefficients 0.70 and 0.40 to the obtained volume of irrigation water for DI0 treatment, respectively.

The volume of water input to each plot was measured for each irrigation using water volume meters.

Crop management

Seeds of two basil cultivars, Green and Purple, were sown in seedling trays under control temperature of 25–30 °C on 19 March 2017 and 4 April 2018. The seedlings were transferred to the soil of a controlled greenhouse with temperature between 25 and 30 °C on 17 April 2017 and 1 May 2018. The seedlings in each plot were planted with a space of 10 cm within the row and were irrigated without any water deficit until the basil plants reached average height of 20–25 cm and adapted to the soil conditions, and then irrigation treatments were applied.

Before soil tillage, farmyard manure (30 tons ha^{-1}) was applied to the experimental soil and mixed with the soil to a depth of 15–20 cm in each experimental year. Considering the initial soil composition, plants were fertilized with a water-soluble 12-12-36 NPK fertilizer (2 g per liter of water) about four and eight weeks after seedling stage in 2017 and eight weeks after seedling stage in 2018. Weeds were controlled by hand and no herbicides, pesticides, and chemical fungicides were applied during the growing seasons.

Harvesting of the basil plants was done at the beginning flowering stage. The harvest dates were July 3, August 8, September 6 in 2017 and July 3, August 2 and September 1 in 2018. In each plot after eliminating the side effect (eliminating two side rows of each plot), the basil plants in the two middle rows after eliminating one basil plant from the beginning and end of each plot were selected for the below measurements.

Table 2 | Irrigation dates and amounts at DI0[a] treatment

Date	Amount (mm)	Date	Amount (mm)
May 17, 2017	43.01	May 25, 2018	42.21
May 24, 2017	43.18	May 31, 2018	40.01
May 31, 2017	39.81	June 7, 2018	34.84
June 7, 2017	34.12	June 14, 2018	38.84
June 14, 2017	33.27	June 21, 2018	30.42
June 21, 2017	30.16	June 27, 2018	27.66
June 28, 2017	26.54	July 5, 2018	39.21
July 5, 2017	38.73	July 10, 2018	46.48
July 10, 2017	42.16	July 14, 2018	37.90
July 15, 2017	40.86	July 18, 2018	31.14
July 20, 2017	34.25	July 24, 2018	29.71
July 25, 2017	27.38	July 29, 2018	28.75
July 30, 2017	26.42	August 4, 2018	40.05
August 5, 2017	26.37	August 8, 2018	41.15
August 10, 2017	34.61	August 12, 2018	35.47
August 14, 2017	41.59	August 16, 2018	36.52
August 18, 2017	40.66	August 20, 2018	29.93
August 22, 2017	34.23	August 25, 2018	29.04
August 26, 2017	27.11	August 29, 2018	25.90
August 30, 2017	33.42		
September 3, 2017	25.10		

[a]DI0 denotes 100% of the field capacity.

Measurements and calculations

Fresh leaves of the basil plant represent a separate market from green tops and dried herbs. Since, in this study, plant height, fresh herb yield, fresh leaves yield and dry herb yield were measured as follow:

Plant height (cm). Before each harvest, the plant height as vegetative growth indicator was measured from the ground to the tip of the highest leaf.

Fresh herb yield (kg ha^{-1}). The basil plants were harvested 10 cm above the ground, and immediately weighed to determine the produced plot yield. Next, the plot yield was upscaled to one hectare land.

Fresh leaves yield (kg ha^{-1}). The leaves of the fresh herbs were isolated from the plant and weighed.

Dry herb yield (kg ha^{-1}). The separated leaves and stems were dried at 70 °C for 48 h and thereafter weighed to obtain dry herb weight.

The water balance approach (Andreu *et al.* 1997) was applied to calculate actual crop evapotranspiration (ETa, mm) for each plot:

$$ETa = IW \pm \Delta S - R - D \quad (2)$$

where IW is the total amount of applied irrigation water (mm) from planting to last harvest, ΔS denotes variation of soil water content in crop root zone (mm) as the difference between total soil water available at planting and after the last harvest, R is the surface runoff (mm) and D represents deep percolation loss (mm). For all treatment, the soil water content was measured by the TDR probes (3 points in each plot) at the time of planting and after the last harvest. The values of the R and D parameters were considered zero because the field is flat and the irrigation water amount was controlled and discharge of the emitters was lower than the infiltration rate of the field soil. In addition, water applied with each irrigation was equal to the water deficit in each irrigation treatment and soil water content eventually reached the field capacity in DI0 treatment.

Table 3 | Effect of irrigation and cultivar on basil plant height (cm)

Year	Irrigation	Cultivar	1st harvest	2nd harvest	3rd harvest	Average
2017	DI0	Green	61.59 b	59.57 ab	58.33ab	59.84 b
		Purple	66.03 ab	64.05 a	68.33 a	66.14 a
		Mean	63.81 A	61.82 A	63.33 A	62.99 A
	DI30	Green	64.58 ab	58.66 b	55.78 b	59.67 b
		Purple	69.25 a	62.43 ab	64.67 ab	65.45 a
		Mean	66.91 A	60.54 A	60.22 A	62.56 A
	DI60	Green	62.89 ab	60.03 ab	57.89 ab	60.27 b
		Purple	63.39 ab	60.27 ab	66.56 ab	63.40 ab
		Mean	63.14 A	60.15 A	62.22 A	61.84 A
2018	DI0	Green	60.61 b	60.27 ab	58.40 bc	59.76 a
		Purple	63.61 b	60.80 ab	62.33 a	62.25 a
		Mean	62.11 B	60.53 A	60.36 A	61.00 A
	DI30	Green	67.00 b	58.03 b	56.07 c	63.85 a
		Purple	77.44 a	62.23 a	60.67 ab	63.30 a
		Mean	72.22 A	60.13 A	58.36 A	63.57 A
	DI60	Green	62.39 b	61.67 a	58.07 bc	60.71 a
		Purple	65.67 b	62.67 a	59.67 ab	62.67 a
		Mean	64.03 AB	62.17 A	58.86 A	61.69 A
	Anova	Y	n.s.	n.s.	n.s.	n.s.
		I	**	n.s.	n.s.	n.s.
		Y * I	n.s.	n.s.	n.s.	n.s.
		C	n.s.	**	**	**
		I * C	n.s.	n.s.	n.s.	n.s.
		Y *C	n.s.	n.s.	n.s.	n.s.
		Y * I * C	n.s.	n.s.	n.s.	n.s.

Within a column for each year, values followed by different letters are significantly different at $P < 0.05$ by Fisher's LSD test (lowercase letters for interaction of irrigation and cultivar and uppercase letters for irrigation treatment).
DI0, DI30 and DI60 are 100, 70 and 40% of the field capacity, respectively.
Y, I and C represent year, irrigation treatment and cultivar, respectively.
** and * are significance at the 0.01 and 0.05 probability levels, respectively. n.s. denotes non-significance.

Precipitation amount was not included in the equation due to the experiment was conducted in a controlled conditions without allowing water to penetrate. The capillary rise was assumed to be zero because of the very deep level of groundwater in the study area.

The CWP for the fresh leaves (CWP-FL), fresh herb (CWP-FH), and dry herb (CWP-DH) were estimated by dividing the yield (kg ha^{-1}) to the total actual crop evapotranspiration (m^3 ha^{-1}).

The effect of water stress on the fresh leaves yield as important part of basil plant for each experimental year and each cultivar was determined applying the Steward's model as follow (Doorenbos & Kassam 1979):

$$\left(1 - \frac{Ya}{Ym}\right) = Ky\left(1 - \frac{ETa}{ETm}\right) \tag{3}$$

where *Ya* is the actual fresh leaves yield (kg ha^{-1}), *Ym* represents the maximum fresh leaves yield (under non-limiting conditions, full irrigation, kg ha^{-1}), *Ky* is the yield response factor, *ETa* denotes the actual crop evapotranspiration (mm) corresponding to *Ya* and *ETm* represents the maximum crop evapotranspiration corresponding to *Ym* (mm). Also 1-(Ya/Ym) was defined as relative yield reduction and 1-(ETa/ETm) is relative evapotranspiration reduction.

Statistical analysis

All collected data were statistically analyzed by analysis of variance (ANOVA) and the mean differences were compared by the Fisher's LSD test ($P \leq 0.05$). The relationship between fresh leaves yield and water used by evapotranspiration was evaluated using regression analysis.

RESULTS AND DİSCUSSİON

Plant height

Analysis of variance indicated that irrigation treatments had a significant effect on the plant height only for the first harvest (Table 3). There was a significant difference between heights of two cultivars at all harvests except the first one (Table 3). Year and interactions of Y × I, I × C, Y × C and Y × I × C had no significant effects on the height of basil plant at any harvests (Table 3).

Average across two cultivars for the first harvest, the maximum values of the basil height were observed at DI30 treatment as 66.91 cm and 72.22 cm in 2017 and 2018, respectively (Table 3). Also for both the study years, DI30 treatment resulted in a maximum average plant height of 69.57 cm (Table 4). However, decrease in plant height due to DI on the basil plant has been documented by Rhizopoulou & Diamantoglou (1991), Moeini Alisha *et al.* (2006) and Ekren *et al.* (2012).

Average across irrigation treatments, Purple basil height in the second and third harvests and average three harvests were more than Green basil height by 4.76%, 16.03% and 8.46% in 2017 and 3.18%, 5.88% and 2.11% in 2018, respectively (Table 3). As seen in Table 4, average height of Purple basil for two study years was higher than that of Green basil. The result was consistent with the ones reported by Goldani (2012).

Fresh leaves yield

The irrigation treatments, cultivar and year had significant effects on fresh leaves yield in all harvests except first harvest for year effect (Table 5). There were significant interactions of Y × I, I × C, Y × C and Y × I × C on fresh

Table 4 | Average plant height values (cm) for and between both years

Treatments	1st harvest	2nd harvest	3rd harvest	Average
Irrigation				
DI0	62.96 b	61.17 a	61.85 a	61.99 a
DI30	69.57 a	60.34 a	59.29 a	63.07 a
DI60	63.58 b	61.16 a	60.54 a	61.76 a
Cultivar				
Green	65.82 a	59.71 b	57.42 b	60.98 b
Purple	64.91 a	62.07 a	63.70 a	63.56 a
Year				
First	64.62 a	60.84 a	61.93 a	62.46 a
Second	66.12 a	60.94 a	59.20 a	62.09 a

Within a column for each section, values followed by different letters are significantly different at $P < 0.05$ by Fisher's LSD test.
DI0, DI30 and DI60 are 100, 70 and 40% of the field capacity, respectively.

Table 5 | Effect of irrigation and cultivar on fresh leaves yield of basil plant (kg ha^{-1})

Year	Irrigation	Cultivar	1st harvest	2nd harvest	3rd harvest	Total
2017	DI0	Green	2962.67 a	3113.78 a	3214.67 a	9291.11 a
		Purple	1663.11 c	1578.33 c	2171.22 cd	5412.67 d
		Mean	2312.89 A	2346.06 A	2692.94 A	7351.89 A
	DI30	Green	2873.22 a	3078.44 a	2619.11 b	8570.78 b
		Purple	1981.89 b	2193.78 b	1757.22 d	5932.89 c
		Mean	2427.56 A	2636.11 A	2188.17 B	7251.83 A
	DI60	Green	2124.78 b	2179.78 b	1754.00 d	6058.56 c
		Purple	1317.33 d	1396.00 c	2259.00 bc	4972.33 d
		Mean	1721.06 A	1787.89 B	2006.50 B	5515.44 B
2018	DI0	Green	2748.79 a	2639.00 a	2830.56 a	8218.35 a
		Purple	2193.77 b	1815.56 c	1948.78 c	5958.10 c
		Mean	2471.28 A	2227.28 A	2389.67 A	7088.23 A
	DI30	Green	2363.48 b	2442.44 b	2399.33 b	7205.26 b
		Purple	2273.56 b	1836.22 c	2000.67 c	6110.45 c
		Mean	2318.52 A	2139.33 A	2200.00 A	6657.85 B
	DI60	Green	1546.93 c	1604.56 d	1542.22 d	4693.71 d
		Purple	1575.70 c	1243.89 e	1229.55 e	4049.15 e
		Mean	1561.32 B	1424.22 B	1385.89 B	4371.43 C
Anova		Y	n.s.	**	**	**
		I	**	**	**	**
		Y * I	*	*	**	**
		C	**	**	**	**
		I * C	**	**	**	**
		Y *C	**	**	n.s.	**
		Y * I * C	n.s.	n.s.	**	*

Within a column for each year, values followed by different letters are significantly different at $P < 0.05$ by Fisher's LSD test (lowercase letters for interaction of irrigation and cultivar and uppercase letters for irrigation treatment).
DI0, DI30 and DI60 are 100, 70 and 40% of the field capacity, respectively.
Y, I and C represent year, irrigation treatment and cultivar, respectively.
** and * are significance at the 0.01 and 0.05 probability levels, respectively. n.s. denotes non-significance.

leaves yield in all harvests except third for interaction of Y × C and first and second harvests for interaction of Y × I × C (Table 5).

Average across two cultivars, the highest fresh leaves yield in all harvests and total of them in two experimental year except first and second harvest in 2017 were obtained in DI0 treatment (Table 5). As seen from the fresh leaves yield average for the study years in Table 6, fresh leaves yield decreased with decreasing irrigation water applied, however there was no significant difference between DI0 and DI30 treatments. Decreasing amount irrigation to 40% of the field capacity (DI60) significantly decreased fresh leaves yield compared to the full irrigation at all harvests (Table 4). Total values of fresh leaves yield in the DI60 treatment decreased by 31.53% relative to the DI0 treatment (Table 6). Water stress leads to tissue water content losses, which decrease cell turgor pressure, thereby preventing cell elongation and division causing plant growth reduction (Shao *et al.* 2007). Similar results of basil leaves yield reduction with the decreased water availability, as well as for the harvest periods, were reported by Moeini Alishah *et al.* (2006) and Jose *et al.* (2016).

Table 6 | Average yield values (kg ha^{-1}) for and between both years

Treatments	Fresh leaves yield				Fresh herb yield				Dry herb yield			
	1st harvest	2nd harvest	3rd harvest	Total	1st harvest	2nd harvest	3rd harvest	Total	1st harvest	2nd harvest	3rd harvest	Total
Irrigation												
DI0	2392.08 a	2286.67 a	2541.31 a	7220.05 a	25544.63 a	22163.52 b	32079.26 a	79787.41 a	3831.69 a	3324.53 b	4811.89 a	11968.11 a
DI30	2373.04 a	2387.72 a	2194.08 b	6954.84 a	24123.33 a	24862.96 a	24646.48 b	73632.78 ab	3618.50 a	3729.44 a	3696.97 b	11044.92 ab
DI60	1641.19 b	1606.06 b	1696.19 c	4943.44 b	22980.74 a	22972.22 ab	25115.74 b	71068.70 b	3447.11 a	3445.83 ab	3767.36 b	10660.36 b
Cultivar												
Green	2436.64 a	2509.67 a	2393.31 a	7339.63 a	26860.62 a	24868.89 a	28556.29 a	80285.8 a	4029.09 a	3730.33a	4283.44 a	12042.87 a
Purple	1834.23 b	1677.30 b	1894.41 b	5405.93 b	21571.85 b	21796.91 b	26004.69 a	69373.46 b	3235.78 b	3269.54 b	3900.70 a	10406.02 b
Year												
First	2153.83 a	2256.69 a	2295.87 a	6706.39 a	22810.74 a	25581.48 a	32288.89 a	80681.11 a	3421.61 a	3837.22 a	4843.33 a	12102.17 a
Second	2117.04 a	1930.28 b	1991.85 a	6039.16 b	25621.73 a	21084.32 b	22272.10 b	68978.10 b	3843.26 a	3162.65 b	3340.81 b	10346.72 b

Within a column for each section, values followed by different letters are significantly different at $P < 0.05$ by Fisher's LSD test.
DI0, DI30 and DI60 are 100, 70 and 40% of the field capacity, respectively.

Average across irrigation treatments, the Green basil had the highest fresh leaves yield at all harvests in 2017 and 2018 (Table 5). As seen in Table 6, fresh leaves yield average of Green basil was higher than that of Purple basil in all harvests by 24.72%, 33.17%, 20.85% and 26.34% in the first to third harvests and total of them, respectively. The fresh leaves yield was found to be higher than the results of Jose *et al.* (2016). It is known that the fresh yield of the basil plant is controlled by various factors such as plant density, fertilization, irrigation and genotype, and is moderately affected by the environmental factors (Penka 1978; Arabaci & Bayram 2004).

In the water stress conditions, Purple basil cultivar mostly performed better than Green basil cultivar. For example, with decreasing irrigation to the 40% of the field capacity, total fresh leaves yield of Green basil cultivar decreased by 34.79% and 42.89% in 2017 and 2018, whereas fresh leaves yield of Purple basil decreased by 8.13 and 32% in 2017 and 2018, respectively (Table 5).

The fresh leaves yield in the first experimental year was higher than that in the second year (Table 6). This can be attributed to difference in radiation in two experimental year. In the first study year, the length of basil growing season was 142 days and basil plant received 2370.88 MJ m^{-2} radiation, while in the second year these values were 123 days and 2048.99 MJ m^{-2}, respectively (Figure 1). The longer growing season and higher cumulative radiation resulted in a significant increase in fresh leaves yield in 2017 due to increasing photosynthesis and growth.

Fresh and dry herb yield

The irrigation treatments, cultivar and year had significant effects on fresh and dry herb yield at all harvests (Tables 7 and 8). There was significant interactions between Y × I, I × C, Y × C and Y × I × C and on fresh and dry herb yields at all harvests except first harvest for Y × I and Y × I × C, first and second harvest for I × C and third harvest for Y × C (Tables 7 and 8).

The fresh and dry herb yields increased in parallel to the volume of applied irrigation water (Tables 6–8). Average across two cultivars at all harvests except the second in 2017 and 2018, the highest values of fresh and dry herb yield were obtained in the DI0 treatment (Tables 7

Table 7 | Effect of irrigation and cultivar on fresh herb yield of basil plant (kg ha^{-1})

Year	Irrigation	Cultivar	1st harvest	2nd harvest	3rd harvest	Total
2017	DI0	Green	29456.29 a	26555.55 b	43091.85 a	99103.70 a
		Purple	18874.81 b	19066.67 c	35945.93 b	73887.41 d
		Mean	24165.56 A	22811.11 B	39518.89 A	86495.55 A
	DI30	Green	27518.52 a	30911.85 a	30500.74 cd	88931.11 b
		Purple	15848.89 b	24844.44 b	22311.11 e	63004.44 e
		Mean	21683.70 A	27878.15 A	26405.93 B	75967.78 B
	DI60	Green	28072.59 a	27360.74 b	28197.78 d	83631.11 bc
		Purple	17093.33 b	24749.63 b	33685.93 bc	75528.89 cd
		Mean	22582.96 A	26055.18 AB	30941.85 B	79580.00 AB
2018	DI0	Green	27090.37 a	21257.78 a	27241.48 a	75589.63 a
		Purple	26757.04 a	21774.07 a	22037.78 ab	70568.89 b
		Mean	26923.7 A	21515.93 AB	24639.63 A	73079.26 A
	DI30	Green	25934.07 ab	22215.56 a	22322.22 ab	70471.85 b
		Purple	27191.85 a	21480.00 a	23451.85 ab	72123.70 ab
		Mean	26562.96 A	21847.78 A	22887.04 A	71297.78 A
	DI60	Green	23091.85 b	20911.85 a	19983.70 b	63987.41 c
		Purple	23665.18 b	18866.67 b	18595.56 b	61127.41 c
		Mean	23378.51 A	19889.26 B	19289.63 A	62557.41 B
	Anova	Y	**	**	**	**
		I	*	**	**	**
		Y * I	n.s.	**	**	**
		C	**	**	*	**
		I * C	n.s.	n.s.	**	*
		Y *C	**	**	n.s.	**
		Y * I * C	n.s.	*	*	**

Within a column for each year, values followed by different letters are significantly different at $P < 0.05$ by Fisher's LSD test (lowercase letters for interaction of irrigation and cultivar and uppercase letters for irrigation treatment).
DI0, DI30 and DI60 are 100, 70 and 40% of the field capacity, respectively.
Y, I and C represent year, irrigation treatment and cultivar, respectively.
** and * are significance at the 0.01 and 0.05 probability levels, respectively. n.s. denotes non-significance.

and 8). For both the study years, DI0 treatment had the highest average values of fresh and dry herb yield at all harvests except the second, although the total value of fresh and dry herb yield in DI30 treatment had no significant difference with DI0 treatment (Table 6). In the second harvest, the basil yield increased with DI (Table 6). The basil dry weight reduced due to the exposure to drought. This could be due to a decrease in the chlorophyll content, and accordingly, photosynthesis efficiency, as stated by Castonguay & Markhart (1991), Viera et al. (1991) and Khalid (2006).

Average across irrigation treatments, the highest fresh and dry herb yield were observed for Green basil (Tables 7 and 8). Also, for both study years, Green basil showed higher yield than Purple basil (Table 6). Similar result was reported by Bekhradi et al. (2015). Various environmental factors such as water stress affecting the aromatic plants growth (Burbott & Loomis 1969). In addition to the environmental factors, genetic differences can also affect the basil yield (Ekren et al. 2012).

The effect of DI on fresh and dry herb yield was significantly different depending on the genotype and year. In

Table 8 | Effect of irrigation and cultivar on dry herb yield of basil plant (kg ha^{-1})

Year	Irrigation	Cultivar	1st harvest	2nd harvest	3rd harvest	Total
2017	DI0	Green	4418.44 a	3983.33 b	6463.78 a	14865.56 a
		Purple	2831.22 b	2860.00 c	5391.89 b	11083.11 d
		Mean	3624.83 A	3421.67 B	5927.83 A	12974.33 A
	DI30	Green	4127.77 a	4636.77 a	4575.11 cd	13339.67 b
		Purple	2377.33 b	3726.67 b	3346.67 e	9450.67 e
		Mean	3252.56 A	4181.72 A	4641.28 B	11395.17 B
	DI60	Green	4210.89 a	4104.11 b	4229.67 d	12544.67 bc
		Purple	2564.00 b	3712.44 b	5052.89 bc	11329.33 cd
		Mean	3387.44 A	3908.28 AB	3960.89 B	11937.00 AB
2018	DI0	Green	4063.56 a	3188.67 a	4086.22 a	11338.44 a
		Purple	4013.56 a	3266.11 a	3305.67 ab	10585.33 b
		Mean	4038.56 A	3227.39 AB	3695.94 A	10961.89 A
	DI30	Green	3890.11 ab	3332.33 a	3348.33 ab	10570.78 b
		Purple	4078.78 a	3222.00 a	3517.78 ab	10818.56 ab
		Mean	3984.44 A	3277.17 A	3433.06 A	10694.67 A
	DI60	Green	3463.78 b	3136.78 a	2997.56 b	9598.11 c
		Purple	3549.78 b	2830.00 b	2789.33 b	9169.11 c
		Mean	3506.78 B	2983.39 B	2893.44 A	9383.61 B
	Anova	Y	**	**	**	**
		I	*	**	**	**
		Y * I	n.s.	**	**	**
		C	**	**	*	**
		I * C	n.s.	n.s.	**	*
		Y *C	**	**	n.s.	**
		Y * I * C	n.s.	*	*	**

Within a column for each year, values followed by different letters are significantly different at $P < 0.05$ by Fisher's LSD test (lowercase letters for interaction of irrigation and cultivar and uppercase letters for irrigation treatment).
DI0, DI30 and DI60 are 100, 70 and 40% of the field capacity, respectively.
Y, I and C represent year, irrigation treatment and cultivar, respectively.
** and * are significance at the 0.01 and 0.05 probability levels, respectively. n.s. denotes non-significance.

2017, the fresh and dry herb yield of Green basil significantly reduced due to 40% DI, probably due to the large vegetative growth, while in Purple cultivar, irrigation treatments did not have much effect on the yields (Tables 7 and 8). While, in 2018, DI reduced fresh and dry herb yield of both cultivars in I40 treatment compared to the control (Tables 7 and 8).

The fresh and dry herb yields were higher in the first experimental year compared to the second year (Table 6) depending on climate conditions and next, plant vegetative growth.

Crop evapotranspiration

Year and irrigation treatment had significant effect on the crop evapotranspiration (Table 9). No significant cultivar and interaction between $Y \times I \times C$ for crop evapotranspiration were observed, however there were interactions of $I \times C$ and $Y \times C$ on crop evapotranspiration (Table 9).

Average across two cultivars, crop evapotranspiration in DI30 and DI60 treatments declined by 42.25% and 64.76% in 2017 and 22.68% and 33.95% in 2018, compared to the DI0 treatment (Table 9). As seen from

Table 9 | Effect of irrigation and cultivar on crop evapotranspiration (ET, m^3 ha^{-1}) and water use efficiencies (CWP, kg m^{-3})

Year	Irrigation	Cultivar	ET	CWP-FL	CWP-FH	CWP-DH
2017	DI0	Green	15851.48 b	0.59 d	6.25 d	0.94 d
		Purple	16568.15 a	0.33 e	4.46 e	0.67 e
		Mean	16209.81 A	0.46 C	5.36 C	0.80 C
	DI30	Green	9402.22 c	0.91 b	9.47 c	1.42 c
		Purple	9318.89 c	0.64 d	6.78 d	1.02 d
		Mean	9360.55 B	0.77 B	8.13 B	1.22 B
	DI60	Green	5511.70 d	1.10 a	15.22 a	2.28 a
		Purple	5912.78 d	0.84 c	12.77 b	1.91 b
		Mean	5712.24 C	0.97 A	13.99 A	2.10 A
2018	DI0	Green	9007.78 a	0.91 a	8.38 bc	1.26 bc
		Purple	9359.44 a	0.64 c	7.54 c	1.13 c
		Mean	9183.61 A	0.77 B	7.96 B	1.19 B
	DI30	Green	7402.78 b	0.97 a	9.51 ab	1.43 ab
		Purple	6799.45 bc	0.90 a	10.63 a	1.59 a
		Mean	7101.11 A	0.94 A	10.07 A	1.51 A
	DI60	Green	6364.07 cd	0.74 b	10.12 a	1.52 a
		Purple	5767.78 d	0.70 bc	10.61 a	1.59 a
		Mean	6065.93 A	0.72 B	10.36 A	1.55 A
	Anova	Y	**	**	n.s.	n.s.
		I	**	**	**	**
		Y * I	**	**	**	**
		C	ns	**	**	**
		I * C	*	*	n.s.	n.s.
		Y *C	*	**	**	**
		Y * I * C	ns	**	*	*

Within a column for each year, values followed by different letters are significantly different at $P < 0.05$ by Fisher's LSD test (lowercase letters for interaction of irrigation and cultivar and uppercase letters for irrigation treatment).
CWP-FL, CWP-FH and CWP-DH denote crop water productivity for fresh leaves yield, fresh herb yield and dry herb yield, respectively.
DI0, DI30 and DI60 are 100, 70 and 40% of the field capacity, respectively.
Y, I and C represent year, irrigation treatment and cultivar, respectively.
** and * are significance at the 0.01 and 0.05 probability levels, respectively. ns denotes non-significance.

the total crop evapotranspiration average for the study years in Table 9, crop evapotranspiration decreased as amount of irrigation water applied declined, with the maximum value was observed in DI0 treatment (12,696.71 m^3 ha^{-1}).

DI0 treatment for Purple basil cultivar had the highest crop evapotranspiration in two years, while the lowest crop evapotranspiration was obtained in DI60 treatment for Purple basil and DI60 treatment for Green basil in 2017 and 2018, respectively (Table 9).

The crop evapotranspiration in first experimental year was more than that in the second year (Table 10). The higher solar radiation in 2017 leaded to more crop evapotranspiration compared to the 2018 (Figure 1).

Crop water productivity

CWP-FL was significantly affected by irrigation, cultivar, year and their interaction effects, while CWP-FH and CWP-DH significantly affected by irrigation, cultivar and

Table 10 | Average crop evapotranspiration (ET, m^3 ha^{-1}) and crop water productivity (CWP, kg m^{-3}) values for and between both years

Treatments	ET	CWP-FL	CWP-FH	CWP-DH
Irrigation				
DI0	12696.71 a	0.57 b	6.28 c	0.94 c
DI30	8230.83 b	0.84 a	8.94 b	1.34 b
DI60	5889.08 c	0.84 a	12.08 a	1.81 a
Cultivars				
Green	8923.34 a	0.82 a	9.00 a	1.35 a
Purple	8954.41 a	0.60 b	7.75 b	1.16 b
Year				
First	10427.54 a	0.73 b	9.16 a	1.37 a
Second	7450.23 b	0.81 a	9.47 a	1.42 a

Within a column for each section, values followed by different letters are significantly different at $P < 0.05$ by Fisher's LSD test.
CWP-FL, CWP-FH and CWP-DH denote crop water productivity for fresh leaves yield, fresh herb yield and dry herb yield, respectively.
DI0, DI30 and DI60 are 100, 70 and 40% of the field capacity, respectively.

interactions between Y × I, Y × C and Y × I × C (Table 9). In general, in both years, CWP increased when the irrigation was decreased, although, the highest CWP-FL in 2018 was obtained in DI60 treatment (Table 9). The highest average CWP-FL, CWP-FH and CWP-DH for the study years were obtained in the DI60 treatment (0.84, 12.08 and 1.81 kg m^{-3}), respectively (Table 10). DI30 and DI60 treatments were in the same statistical group with the value of a 0.84 kg m^{-3} CWP-FL (Table 10). Increasing the CWP value with decreasing the amount of water applied in basil plant reported by Agami *et al.* (2016). In contrast, in previous study by Ekren *et al.* (2012), the irrigation water use efficiency was not affected by the irrigation water levels because yields obtained for unit irrigation water applied were relatively close to each other.

Regarding the cultivars, the CWP-FL, CWP-FH and CWP-DH were found to be higher in the Green cultivar with 0.87 kg m^{-3}, 10.31 kg m^{-3} and 1.55 kg m^{-3} in 2017 and 0.88 kg m^{-3}, 9.34 kg m^{-3} and 1.43 kg m^{-3} in 2018, respectively (Table 9). For both study years, Green cultivar clearly indicated the highest CWP-FL, CWP-FH and CWP-DH (Table 10).

In both cultivar, CWP-FL in 2018 increased with DI to 70% of the field capacity and then decreased from DI30 to DI60 treatment while the CWP-GL in 2017 and CWP-FH and CWP-DH in both experimental years, it increased with DI in both basil cultivar (Table 9). In 2017, DI increased CWP-FL by 86.44% and 154.54% and CWP-FH by 143.52% and 186.32% and CWP-DH by 142.55% and 185.07% compared to control in I40 Green and Purple cultivars, respectively (Table 10). In 2018, decreasing the amount of irrigation water to 40% of the FC, increased CWP-FL by 18.68% and 9.37% and CWP-FH by 20.76% and 3.07% and CWP-DH by 20.63% and 40.71% compared to control for Green and Purple cultivars, respectively (Table 10). Based on the results, Purple basil was more sensitive to the applied water amount in the first study year. CWP-FL in the second experimental year was higher than the first experimental year, due to less crop evapotranspiration in 2018 (Table 10).

Crop–water relationship

Evaluation of the effects of crop evapotranspiration on fresh leaves production of two basil cultivars was performed by regression analysis (Figure 2). A linear relationship was observed between crop evapotranspiration and the fresh leaves production of two basil cultivars for two years of the experiment (Figure 2). The coefficients of determination between the fresh leaves yield and crop evapotranspiration were similar for the two basil cultivars in 2018 ($r^2 = 0.87$), but the coefficient for Purple basil was higher than Green basil in 2017 ($r^2 = 0.81$ and $r^2 = 0.99$ for Green and Purple basil, respectively) (Table 11). For two basil cultivars, both the values of intercepts and the slope of the regression lines varied widely over the two years and steeper slope of regression line was observed in 2018 (Table 11). The slope, which indicates the increase in fresh leaves production for each unit increase in crop evapotranspiration were 0.29 kg m^{-3} and 1.27 kg m^{-3} for Green basil and 0.33 kg m^{-3} and 0.85 kg m^{-3} for Purple basil in 2017 and 2018, respectively (Table 11). The higher slope means the higher efficiency of applied water in fresh leaves yield production of basil plant. The difference in the slope of regression line between two experimental years is probably due to differences in weather conditions. Our results showed a similarity to the results reported by Payero *et al.* (2006), who indicated the relationships between maize yield and seasonal crop evapotranspiration are inconsistent and change with location. Combining data for 2017 and

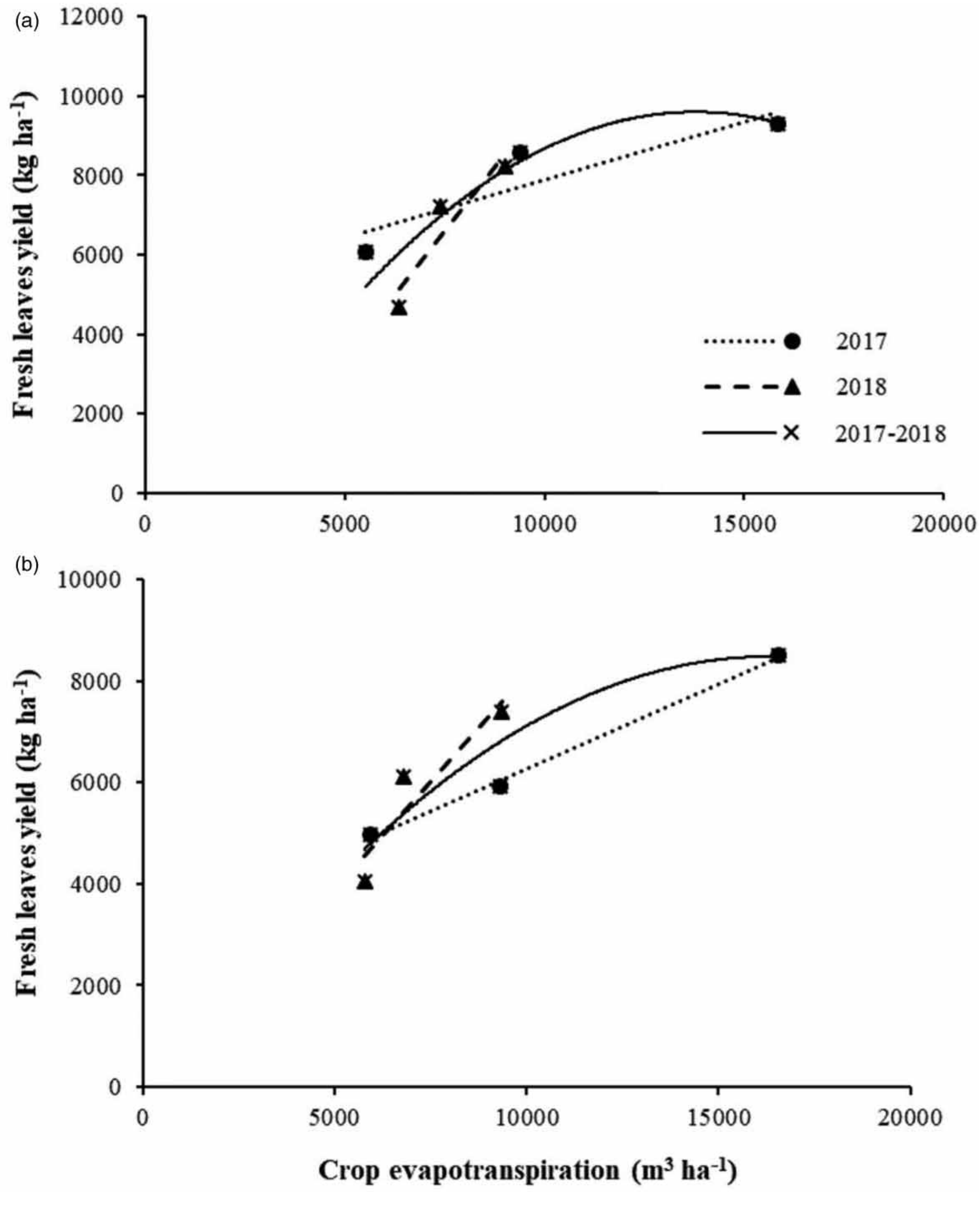

Figure 2 | Relationship between fresh leaves yield and crop evapotranspiration for (a) Green and (b) Purple basil.

2018, the graph of fresh leaves production versus crop evapotranspiration for Green and Purple cultivars indicated a deviation from linearity to a second order relationship (Figure 2). Namely, crop evapotranspiration maximized fresh leaves yield up to the point when additional crop evapotranspiration did not lead to additional yield and more irrigation water applied to the basil plant reduced the fresh yield due to the adverse effect of the excess water on the basil plant. The coefficients of determination were 0.82 and 0.84 for Green and Purple cultivars, respectively (Table 11).

Yield response factor (Ky)

For each of the study cultivars, good linear relationships between relative water consumption and fresh leaves

Table 11 | Relationships between fresh leaves yield and crop evapotranspiration

Cultivar	Experimental year	Regression equation	Regression coefficient
Green	2017	y = 0.2924x + 4975.2	$R^2 = 0.81$
	2018	y = 1.2733x − 2960.3	$R^2 = 0.87$
	2017–2018	y = −6E-05 × ² + 1.7773x − 2649.6	$R^2 = 0.82$
Purple	2017	y = 0.3347x + 2920.8	$R^2 = 0.99$
	2018	y = 0.8511x − 367.44	$R^2 = 0.87$
	2017–2018	y = −3E-05 × ² + 1.1103x − 589.49	$R^2 = 0.84$

production were obtained in all two years (Figure 3). According to Doorenbos & Kassam (1979), the slope of the regression line in Figure 3 denotes the Ky. The Ky values were 0.50 and 1.40 for Green basil and 0.65 and 1.08 for Purple basil in 2017 and 2018, respectively. The higher Ky value (i.e., steeper slope of the regression line) leads to a more reduction of fresh leaves production for a specific reduction in evapotranspiration due to water deficits (Kresovic *et al.* 2016). The experiment was carried out under controlled conditions of the greenhouse and it was expected that Ky for two experimental years would be close to each other. However, the differences in fresh leaves production among the years (Table 6) were the result of different crop response to water, which in turn relates to irrigation regime and radiation conditions (Figure 1). According to the Ky values for two cultivars (Table 12), in the first study year, Purple basil was more sensitive to the water deficit while in 2018 Green basil was more sensitive. It seems that in the favorable radiation conditions, Green basil is more appropriate option for applying DI than Purple basil, while in a radiation conditions similar to 2018, Purple basil performs better. Based on the average Ky value for the both years (Table 12), Green and Purple basil showed similar response to the water stress, with the Ky values of 0.70

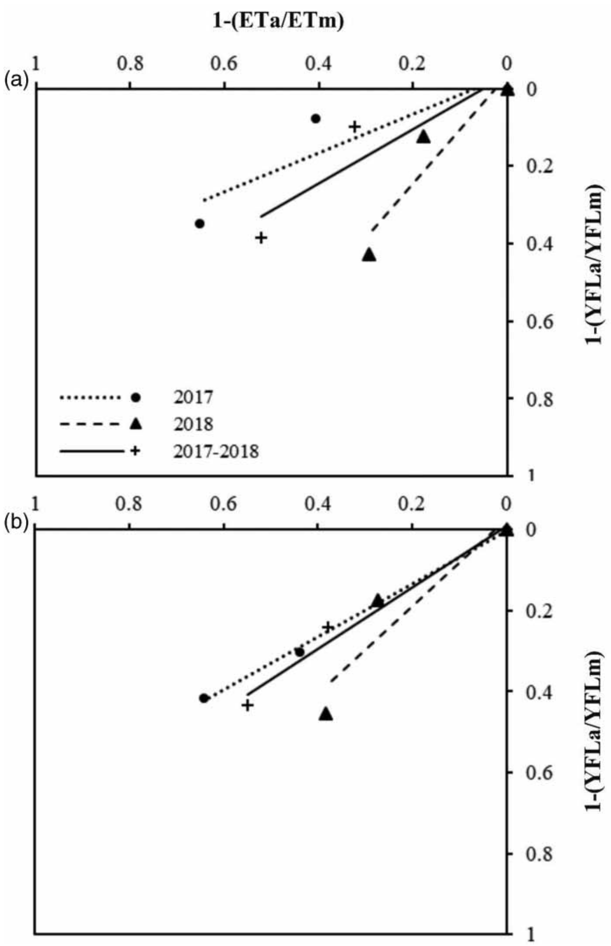

Figure 3 | Relationship between relative evapotranspiration deficit (1-ETa/ETm) and relative yield decrease (1-Ya/Ym) for (a) Green and (b) Purple basil.

Table 12 | Relationships between relative evapotranspiration deficit and relative yield decrease

Cultivar	Experimental year	Regression equation	Regression coefficient	Ky
Green	2017	1-(YFLa/YFLm) = 0.4988(1-(ETa/ ETm) − 0.0343	0.81	0.50
	2018	1-(YFLa/YFLm) = 1.3956(1-(ETa/ ETm) − 0.0354	0.87	1.40
	2017–2018	1-(YFLa/YFLm) = 0.6966(1-(ETa/ ETm) − 0.0349	0.84	0.70
Purple	2017	1-(YFLa/YFLm) = 0.6524(1-(ETa/ ETm) +0.004	0.99	0.65
	2018	1-(YFLa/YFLm) = 1.0765(1-(ETa/ ETm) − 0.0268	0.87	1.08
	2017–2018	1-(YFLa/YFLm) = 0.7631(1-(ETa/ ETm) − 0.011	0.98	0.76

Ky represents yield response factor.

and 0.76 for Green and Purple basil, respectively. Since the Ky values were lower than one, the basil plant can be considered as tolerant plant to water deficit. The obtained Ky value is in agreement with those reported by Saeedinia *et al.* (2019) for *Satureja hortensis*. However, our results showed lower values than the value reported by Pejic *et al.* (2017). They obtained the Ky value of 0.22 for the basil plant, due to rainy weather conditions during the growing season.

CONCLUSION

Throughout this study, DI was examined for the two basil cultivars. It was found that by increasing the harvest number, basil production did not show a considerable decrease, and even some increased production was monitored. Therefore, it seems logical to have three harvests of basil plant even under water deficit treatments in greenhouse conditions.

The growth of plant cells is the most important process that is affected by water shortage (Erken *et al.* 2012). When there is a reduction in the growth of cells, we can recognize the size of plant through the smaller size of leaves or decrease in plant height (Hsiao 1973). In this study, deficit irrigation had a greater effect on the leaves production than the height of basil plant. Only in the first harvest, the height of basil plant at DI30 treatment was significantly higher than the other irrigation treatments. Basil plant yields decreased and CWP increased depending on the water deficit levels; however, there was no significant difference between fresh leaves production and fresh and dry herb production under DI0 and DI30 treatments. As a result, DI at 70% of the FC was more effective in saving irrigation water along with a good marketable yield of the basil plant compared to 100% of the FC treatment and furrow irrigation practice by farmers in the greenhouse conditions.

A polynomial relationship was stablished between fresh leaves production and consumed water, but crop Ky showed a linear relationship between the relative reduction in water applied vs. the relative reduction in yield with an average value of 0.73. According to the average Ky value for the both experimental year, basil plant especially Green cultivar when grown in greenhouse conditions, can be considered as a water stress tolerant crop.

The results of the study could be used as a good platform for greenhouse basil producers to optimize the use of irrigation water.

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DECLARATION OF INTEREST STATEMENT

The author declare to have no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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