DETERMINATION OF OPTIMAL DEFICIT IRRIGATION STRATEGIES FOR YIELD AND YIELD COMPONENTS OF LAVENDER (*LAVANDULA ANGUSTIFOLIA* MILL.) IN SEMI-ARID CONDITIONS

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Abstract. The lavender is one of the most distinguished raw materials for the pharmaceutical and cosmetic industries. The rising demand for lavender in the industry necessitates the investigations for methods that will obtain more yield by using less water since drought means an increasing threat in the world. The current study examines the impact of various irrigation strategies of the growth and water-yield relationships in lavender plants using the drip irrigation method. The experiment was conducted during the growing seasons of 2020 and 2021 in field conditions in western Turkey. The Class A-Pan evaporation method and gravimetric method were used as monitoring techniques in irrigation scheduling. In the study, four different irrigation levels (100%, 67%, 33%, and 0%-rainfed) were applied in three replications in randomized blocks. The crop evapotranspiration ranged between 144.4-703.8 mm and 157.0-739.0 mm in the trial years, respectively. According to the results, the highest green herb yield was harvested from fully irrigated and gravimetrically monitored plots in trial years, with yields of 5298.0 and 5840 kg ha^{-1}. On the other hand, the lowest yield was obtained from rainfed plots. Drug herb yield and yield components were negatively influenced by decreasing water levels. Average water use efficiency (WUE) values varied between 0.74-2.68 kg m^{-3} and irrigation water use efficiency (IWUE) ranged between 0.86-2.72 kg m^{-3}. Lavender sensitivity to water stress (k_y) was determined to have an average value of 0.31. In the case that there is a need to impose a constraint on the water source, it is recommended to use the P2 and G2 treatments, which can save up to 33% of water, for scheduling the irrigation of lavender plants.
Keywords: *drip irrigation, irrigation levels, evapotranspiration, yield response factor, yield-water relationship*

Introduction

Lavender (Lavandula spp.), the plant from the Lamiaceae family is a perennial herb grown for its flowers. It has been widely used either dried or as an essential oil (Cavanagh and Wilkinson, 2002). The lavender plant is naturally grown in the western Mediterranean, including southern France, the middle regions of Italy, Spain, and Greece. British lavender (*Lavandula angustifolia* Mill.) is among the species with high economic value (Sönmez et al., 2018). The cultivation of medicinal and aromatic plants in Turkey was quite limited until the early 2000s, and the demand was primarily met by collecting them from nature. In recent years, there has been a growing interest in medicinal and aromatic plants among the general population. This has led to an increase in cultivation, use, and trade, supported by state-funded growing projects. In Turkey, the total cultivated area has reached to 4 718 ha with a total production of 7 722 tons (Bayram et al., 2010; TUIK, 2022). This trend has led to an increase in research and

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development activities in breeding studies, as well as the number of registered varieties in Turkey (TAGEM, 2021).

Climate change can have a significant impact on lavender plantations and their irrigation practices, resulting in increased water stress and potential challenges for lavender cultivation. Although the government in Turkey has been supporting the growth of medicinal and aromatic plants in recent years, the consequences of climate change have brought several problems for growers, including drought, more frequent heat waves, and water deficits. Drought stress should be considered as a threat to the development and yield of plants (Shabankareh et al., 2021). Therefore, strategies should be developed to mitigate its effects. Even though lavender plants have the ability to survive in rainfed conditions, cultivated lavender varieties are mostly irrigated using surface irrigation methods. Since lavender branches are sensitive to water-induced diseases, the drip irrigation method is recommended for healthy crop growth (Akgül et al., 2019).

As water is regarded as the most vital factor for plant development, the lack of or excess of water is considered a major source of stress (Aqeel et al., 2023). Lavender plants under water deficit showed a reduction in plant growth-related parameters (Chrysargyris et al., 2016). 'Rapido' variety of *L. angustifolia* was found as an outstanding candidate for sustainable lavender growing in the context of climate change, with its high dry floral biomass yield under drought conditions (Saunier et al., 2022). Lower soil moisture content reduced the leaf area, leaf number, and fresh and dry weights of shoots in two different English lavender cultivars (Zhen and Burnett, 2015). Lavender plants, when periodically exposed to water deficit and re-hydration, responded to the water deficit. The plants quickly recovered to their previous physiological status, except for their total C and total N contents (Du and Rennenberg, 2018). Under fully irrigated conditions, yield of fresh and airdried lavender leaves and essential oil content were increased (Sałata et al., 2020). The water use of *Lavandula angustifolia* Mill. was determined as 1191.4 mm in lysimeters by using water balance approach (Noorollahi et al., 2016). As the water supply increases, there was an observed increase in the drug herb yield and leaf yield of oregano (Tokul and Bayram, 2022). Different irrigation water levels influenced the green herb yield, drug herb yield, drug leaf yield and plant height of purple basil (Ekren et al., 2012). Deficit irrigation reduced seed yield, biological yield and water use significantly, but water use efficiency (WUE) was significantly increased in Isabgol and *French psyllium* (Rahimi et al., 2011). Decreasing irrigation intervals increased the biomass and yield of *Plectranthus amboinicus* plants (Sabra et al., 2018). The yield, main stem length, and main stem weight of dill plants exposed to three different irrigation levels showed a significant change at $p < 0.001$ (El-Zaeddi et al., 2017). Water application alters the yield and essential oil content in several aromatic plants (Aqeel et al., 2023).

In the changing climate, plants that previously survived under rainfed conditions are now dependent on irrigation. Conventionel surface irrigation methods using water inefficiently is mostly preferred in lavender growing, therefore, the effect of varying irrigation thresholds on the yield and yield parameters should be investigated. On the other hand, optimization of irrigation scheduling has become a priority in a world that water scarcity becomes widespread. Few research have reported the effects of irrigation on the yield and quality of lavender, but there is a lack of information about the yield-water relationships, yield response factor (k_y) and water consumption of the plant. In the current study, the aim was to determine the water requirement of the lavender crop

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(*Lavandula angustifolia* Mill.) and its relationship with yield and yield components under various irrigation strategies. Additionally, it was aimed to propose an optimum irrigation schedule for the crop.

Materials and methods

Description of the experimental site

The research was carried out in 2020 and 2021 in Aydın Adnan Menderes University, Research and Application Farm of Faculty of Agriculture in Turkey (37° 45′ 53″ northern latitude and 27° 45′ 37″ eastern longitude, at an altitude of 56 m). Mediterranean climate prevails in the region with dry and hot summers and rainy, warm winters. The meteorological data of the experiment area for 2020 and 2021 was obtained from the meteorology station located within the research area (iMETOS 2.0), and presented in *Table 1*.

Table 1. *Meteorological parameters of the experimental area*

Year	Climatic parameter	Months				
		May	June	July	August	September
2020	$Temperature_{mean}$ (°C)	21.0	26.0	28.6	27.6	23.3
	Relative $humidity_{mean}$ (%)	56.9	49.2	48.6	52.9	55.9
	Precipitation (mm)	35.6	16.6	7.5	5.3	15.1
	Evaporation (mm)	161.3	222.1	257.5	231.6	161.9
2021	$Temperature_{mean}$ (°C)	22.1	25.2	29.9	29.2	26.9
	Relative $humidity_{mean}$ (%)	54.9	54.4	47.8	46.9	54.7
	Precipitation (mm)	33.3	20.3	0.0	0.0	0.0
	Evaporation (mm)	175.2	200.2	272.6	247.1	182.8
Long-term average (1970–2019)	$Temperature_{mean}$ (°C)	23.6	26.1	30.9	30.5	25.0
	Relative $humidity_{mean}$ (%)	47.3	47.3	42.2	40.3	48.0
	Precipitation (mm)	93.2	1.1	0.1	0.0	0.5
	Evaporation (mm)	151.9	204.2	269.5	253.6	151.7

The soil properties were investigated in the 0-90 cm depth and are presented in *Table 2.* The soil profile has a sandy-loam texture with a soil bulk density ranging between 1.35 to 1.52 g cm^{-3}. Field capacity and wilting point values ranged from 18.4% to 23.1% and 7.3% to 10.1%. in 0-90 cm soil depth respectively. Total available water capacity is 162 mm in 0.9 m^{-1}.

Table 2. *Soil features of the experimental site*

Soil depth (cm)	Soil texture distribution (%)			Texture class	pH	$CaCO_3$ (%)	EC (dS m^{-1})	Bulk density (g cm^{-3})	*Field capacity		*Wilting point		Available water capacity	
	Sand	Clay	Loam						(%)	(mm)	(%)	(mm	(%)	(mm)
0-30	58.4	13.6	28.0	SL	8.0	11.40	0.54	1.35	23.1	111.5	10.1	40.9	13.0	52.6
30-60	56.4	13.6	30.0	SL	7.9	10.20	0.48	1.45	22.9	99.6	9.4	40.8	13.5	58.8
60-90	68.2	13.6	19.2	SL	7.9	10.56	0.46	1.52	18.4	83.9	7.3	33.2	11.1	50.6

*Dry weight percentage

Agronomic practices

English lavender (*Lavandula angustifolia* Mill.), which has a high yield potential, was used as the research material. The seedlings were grown in pots and transplanted into the experimental plots on February 1, 2020, with a spacing of 1.2 × 0.4 m. Supplemental irrigation was applied to the whole experiment at the transplanting at 40 mm. Before transplantation of the seedlings, 40 kg ha^{-1} $(NH_4)_2SO_4$ fertilizer was applied to the trial area. In the second year of the experiment, 40 kg ha^{-1} NH_4NO_3 was applied to the plots in March. In both years, liquid fertilizer was applied twice through foliar spraying to meet the plants' microelement requirements. Weed control and hoeing were done by hand regularly during the growing season.

Experimental design and treatments

The research was conducted under field conditions using a completely randomized block design with three replications. There were four plant rows in each of the plot (plot area: 24.0 m^2), in order to eliminate the water interaction between plots, two rows were excluded and 12.0 m^2 was regarded as sampling and harvesting area. A view of the experiment located in the research and application farm of the faculty in Aydın province is presented in *Figure 1*.

Figure 1. *The view of the trial in the study site*

In the study, the Class-A Pan evaporation method and the gravimetric method were used in irrigation programming Four irrigation levels (Rainfed treatment, as well as fully irrigated treatment and 33% and 67% times of the full irrigation treatment) were used. P_1 treatment received the total sum of 100% of the pan evaporation that occurred in a 7-day interval, while P_2 and P_3 received 67% and 33% of it, respectively. The irrigation treatments under the gravimetric method were arranged based on the replenishment of soil water depletion. Under gravimetric monitoring treatment, four irrigation levels (IL) were investigated. G_1 represented the fully irrigated treatment, receiving 100% of the water amount needed to bring the soil depth of 0-60 cm to field capacity (control treatment). G_2 and G_3 received 67% and 33% of the amount applied to G_1, respectively. G_4 represented the rainfed treatment. The treatments investigated in the experiment are listed in *Table 3*.

Irrigation water was applied via drip irrigation system installed in the experimental area. The water extracted from the deep well in the research area was used as an irrigation water resource for the experiment. The salinity of the irrigation water is

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0.98 dS m^{-1} with a sodium absorption rate (SAR) of 1.76. The irrigation water is classified as C_3S_1 category and does not pose a threat to lavender irrigation. The irrigation water filtrated through the control unit was conveyed and distributed within the trial area with Φ63 mm PE pipes. The discharge of the inline drippers is 2 L h^{-1} with 25 cm distance on the drip lines. The irrigation was controlled by using valves in the inlets of each plot.

Table 3. *Combination of the treatments investigated in the experiment*

Irrigation program method	Irrigation levels (%)	Treatments
Pan	100	P_1
	67	P_2
	33	P_3
	0	P_4
Gravimetric	100	G_1
	67	G_2
	33	G_3
	0	G_4

In both irrigation program methods, the first scheduled irrigation was launched when 50% of the available water had depleted in the 0.6 m effective rooting depth of the lavender. Irrigation water was applied to the deficit irrigated plots according to the irrigation levels. Soil moisture was monitored by sampling gravimetrically throughout the irrigation period prior to irrigation events. The evaporation amount was determined daily from the Class A-Pan located within the experimental field. The equation used in calculating the amount of irrigation water for pan method is given in *Equation 1* (Kanber, 1984) and for gravimetric method in *Equation 2* (Doorenbos and Pruitt, 1977).

$$V = P_{WA}\, x\, A\, x\, E_{pan}\, x\, k_{pc} \quad \text{(Eq.1)}$$

$$I = \frac{[Pw_{FC} - Pw_{SM}]}{100} \times D \times P_{WA} \times \gamma_s \quad \text{(Eq.2)}$$

In *Equation 1*, V refers to the volume of irrigation water (L), P_{WA} is the wetted percentage (taken 100% for row crops), A is the area of the plot (m^2), E_{pan} is the sum of the evaporation in 7 days interval (mm) and k_{pc} is the pan coefficient. In *Equation 2,* I represents the amount of water applied to D_1 (mm), Pw_{FC} denotes the field capacity (%), Pw_{SM} represents the available soil moisture (%), D indicates the depth of the soil layer (mm), P_{WA} stands for the percentage of the wetted area and γ_S represents the bulk density of the soil (g cm^{-3}). P_{WA} is considered as 100% for row crops.

Evapotranspiration of the lavender plants under different irrigation levels are calculated according to the water balance equation (*Eq. 3*) (Allen et al., 1998).

$$ET = I + P \pm \Delta S_w - D_{Per} - R_{off} \quad \text{(Eq.3)}$$

In the equation, ET refers the evapotranspiration amount (mm), I represents the amount of the irrigation water applied (mm), P indicates the amount of rainfall (mm), ΔS_w is for the amount of the variation in the soil water content in 0.9 m depth (mm). D_{Per} and R_{off} are ignored since they occur in negligible amounts.

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were calculated by the division of the green herb yield (Y) (kg ha^{-1}) by crop evapotranspiration (ET) (mm) and by per unit irrigation water applied (I) (mm) (Howell et al., 1990).

$$WUE = \frac{Y}{ET} \quad \text{(Eq.4)}$$

$$IWUE = \frac{Y}{I} \quad \text{(Eq.5)}$$

The Stewart's model is commonly used to investigate the effect of water stress on yield during the plant growth. By using the relationships between ET, transpiration, irrigation water amount, and yield, water production functions were obtained by a regression analysis based on Stewart's model. The yield response factor (k_y) exhibiting the relationship between the relative reduction in yield and the deficit in relative evapotranspiration was determined using *Equation 6* (Doorenbos and Kassam, 1979).

$$1\text{-}\left(\frac{Y_a}{Y_m}\right) = k_y\left[1\text{-}\left(\frac{ET_a}{ET_m}\right)\right] \quad \text{(Eq.6)}$$

In the equation, Y_a refers to the actual harvested green herb yield and Y_m denotes the maximum harvested green herb yield in kg ha^{-1}, k_y represents the yield response factor, ET_a is the actual evapotranspiration, ET_m is the maximum evapotranspiration in mm. Relative green herb yield reduction is shown as 1-(Y_a/Y_m) and the relative evapotranspiration deficit is given as 1-(ET_a/ET_m).

Analysis and statistical evaluation

Harvesting and sampling was made on 10th and 16th of July in 2020 and 6th and 13th of July in 2021 respectively. In both trial years, the plants were harvested twice and plant height (cm) and spike stem length (mm) values were measured in the second harvest. Green herb yield (kg ha^{-1}), drug herb yield (kg ha^{-1}) and drug/green herb yield ratio (%) were determined separately for each plot by considering both harvest values.

The data collected for yield and yield parameters in the study were assessed by analysis of variance (ANOVA) at 1% and 5% level and the differences between treatments were determined by SPSS software. LSD test was applied at 5% significance level to identify any differences between the groups.

Results

Irrigation and evapotranspiration

Total rainfall amounts during the growing season in the trial years were 29.4 mm in 2020 and 20.3 mm in 2021 respectively (*Table 1*). In comparison to the long-term mean of 1.2 mm, an uneven distribution of higher amounts of rainfall was observed in both experimental years. The irrigation program was launched on June 13, 2020, and ended on August 26, 2020. In 2021, irrigation water was applied between June 5 and August

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14. Irrigation water was applied a total of 8 times in both irrigation program methods in the experimental years.

Irrigation water amount (I), seasonal evapotranspiration (ET), green herb yield, water use efficiency (WUE) and irrigation water use efficiency (IWUE) values for lavender plant in both experimental years are presented in *Table 4*.

Total irrigation water amounts applied to the plots using the pan irrigation method ranged between 197.0-597.1 mm in 2020 and 209.0-633.0 mm in 2021. On the other hand, relatively less irrigation water was applied to gravimetrically monitored plots. The amounts varied between 190.1-576.1 mm in 2020 and 183.0-552.0 mm in 2021. Water use (ET) increased with the increments in irrigation levels and differentiated according to irrigation program methods. The ET data calculated in pan irrigation method varied between 154.9-703.8 mm in 2020 and 165.0-739.0 mm in 2021. Under gravimetric method, the ET values were ranged between 144.4-655.5 in 2020 and 157.0-705.0 mm in 2021. In the study, the lowest crop ET values were obtained from the rainfed treatments (P_4 and G_4), while the highest crop ET data were collected from the plots of fully irrigated P_1 and G_1 treatments. When water use data was examined proportionally, differences were observed in all treatments. In each irrigation program method, water consumption decreased by 35.7% and 26.5% in 2020, and by 30.0% and 31.3% respectively in the P_2 and G_2 treatments, where a water constraint of 33% was applied. A reduction in crop water use was calculated 64.7% and 60.9% for the first trial year and 62.9% and 54.2% for 2021 respectively in P_3 and G_3 treatments, where 67% water restriction was applied.

Considering the yield values of the treatments, the highest green herb yields were obtained from the P_1 and G_1 treatments, where the highest water use was occurred in both irrigation program methods (*Table 4*). The highest green herb yield was harvested from the above-mentioned treatments without any water restriction between 4910.0 kg ha^{-1}-5298.0 kg ha^{-1} in 2020 and 5710.0 kg ha^{-1}-5840.0 kg ha^{-1} in 2021 respectively. The lowest green herb yield was obtained from the rainfed treatments (P_4 and G_4) and green herb yields in other treatments varied between these values.

Water use efficiency (WUE) and irrigation water use (IWUE) efficiency

As presented in *Table 4*, there has been a change in WUE and IWUE values considering the irrigation treatments. WUE and IWUE values were found to be higher in plots irrigated using the gravimetric method compared to plots irrigated using pan evaporation. The lowest WUE and IWUE values were determined from P_1 and G_1 treatments. Accordingly, WUE values varied between 0.70-2.82 kg m^{-3} in the first year of the trial and 0.77-2.54 kg m^{-3} in the second year. IWUE values showed a variation between 0.82-2.57 kg m^{-3} in 2020, while they ranged between 0.90-2.87 kg m^{-3} in 2021. WUE and IWUE values decreased as the amount of irrigation water given to the experimental plots increased. In both experimental years, the highest WUE was obtained from the rainfed plots, with values of 2.82 kg m^{-3} and 2.54 kg m^{-3} for the G_4 treatment and 2.30 kg m^{-3} and 2.19 kg m^{-3} for the P_4 treatment. In terms of water saving, it is obvious that P_4 and G_4 treatments use unit water more effectively. However, with the water limitation made under these circumstances, the yield decreased by 23.2% (G_4) and 27.4% (P_4) in 2020 and 31.7% (G_4) and 36.7% (P_4) in 2021 respectively. On the other hand, P_2 and G_2 treatments saving 33% water are ensuring relatively lower decrease in yield with 5.5% and 5% reduction in 2020 and 7.7% and 2.7% in 2021. In the current study, G_2 treatment in which 67% of irrigation water was applied by gravimetric method exhibited the least decrease in yield.

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Table 4. *Irrigation water amounts, evapotranspiration (I), water use efficiency (WUE) and irrigation water use efficiency (IWUE) and green herb yield of lavender as influenced by irrigation program methods and irrigation levels*

Treatments	2020							2021						
	I (mm)	Water saving (%)	ET (mm)	Yield* (kg ha^{-1})	Relative yield (%)	WUE (kg m^{-3})	(IWUE) (kg m^{-3})	I (mm)	Water saving (%)	ET (mm)	Yield* (kg ha^{-1})	Relative yield (%)	WUE (kg m^{-3})	(IWUE) (kg m^{-3})
P_1	597.1	0.0	703.8	4910.0	100.0	0.70	0.82	633.0	0.0	739.0	5710.0	100.0	0.77	0.90
P_2	400.0	33.0	452.8	4642.0	94.5	1.03	1.16	424.0	33.0	517.0	5270.0	92.3	1.02	1.24
P_3	197.0	67.0	248.4	4129.0	84.1	1.45	2.10	209.0	67.0	274.0	4560.0	79.9	1.66	2.18
P_4	-	100.0	154.9	3565.0	72.6	2.30	-	-	100.0	165.0	3610.0	63.2	2.19	-
G_1	576.1	0.0	655.5	5298.0	100.0	0.81	0.92	552.0	0.0	705.0	5840.0	100.0	0.83	1.06
G_2	386.0	33.0	481.6	5035.0	95.0	1.05	1.30	372.0	33.0	484.0	5680.0	97.3	1.17	1.53
G_3	190.1	67.0	255.8	4882.0	92.1	1.91	2.57	183.0	67.0	323.0	5250.0	89.9	1.63	2.87
G_4	-	100.0	144.4	4070.0	76.8	2.82	-	-	100.0	157.0	3990.0	68.3	2.54	-

*Yields are given as green herb yields (kg ha^{-1})

Water use and yield relationship of lavender

The ANOVA of the green and drug herb yield and some yield components of lavender are given in *Table 5* for *2020* and *Table 6* for 2021 trial years.

Table 5. *Yield and yield components of lavender as influenced by irrigation program methods and irrigation levels (2020)*

		Green herb yield (kg ha^{-1})	**Drug herb yield (kg ha^{-1})**	**Drug/green herb ratio (%)**	**Plant height (cm)**	**Spike stem length (mm)**
Irrigation program method (M)	Pan	4311.6b	2072.0b	47.8	51.5	265.1
	Gravimetric	4821.3a	2339.0a	48.2	52.9	278.9
LSD $_{5\%}$		108.6	107.3			
Irrigation level (IL)	100%	5104.0a	2634.5a	51.5a	54.1	290.0a
	67%	4838.6b	2377.6b	49.1ab	53.2	273.6ab
	33%	4505.6c	2092.0c	46.5bc	52.1	264.9b
	0%	3817.6d	1717.8d	44.9c	49.6	259.8b
LSD $_{5\%}$		153.5	151.3	3.885		21.32
	M	**	**	ns	ns	ns
	IL	**	**	*	ns	*
	M x IL	ns	ns	ns	ns	ns

Means with different letters in the same column indicate significant differences between treatments according to LSD test (n = 3 replicates, $p < 0.05$)
**$p < 0.01$, *$p < 0.05$, ns: not significant

In 2020, the green and drug herb yields were significantly affected by different irrigation programs and irrigation levels at $p < 0.01$. The average of highest green herb yield of gravimetrically monitored plots was 4821.3 kg ha^{-1}. The averages of the plots in which the crop water requirement was fully met gave the highest green herb yields (5104.0 kg ha^{-1}). This was followed by an irrigation level of 67% with an average yield of 4838.6 kg ha^{-1}. The lowest green herb yield was harvested from the rainfed plots. Similar results were observed for drug herb yields. Pan method yielded lower values than gravimetric method and the increments in the irrigation level remarkably increased

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the average drug herb yields at $p < 0.01$ level. However, the M × IL interaction was insignificant in the trial year. When the results of the LSD test were examined in terms of irrigation program methods, the gravimetrically applied irrigation program formed the first group in both green and drug herb yield. Regarding the irrigation levels, four different groups were determined for green and drug herb yield. In terms of green and drug herb yields, the first group included full irrigation (100%), while the second group had 67% IL. 33% IL and rainfed treatments formed the third and fourth groups, respectively. 33% IL and rainfed treatment formed the third and fourth group respectively. Drug/green herb ratio and spike stem length are not significantly influenced by the irrigation program methods, but the irrigation levels had a notable effect at the $p < 0.05$ level on both traits. For both parameters, the averages of the gravimetric method and the 100% IL treatment were higher than those of the other treatments. Lowest average drug/green herb ratio (44.9%) and spike stem length were measured (259.8 mm) at rainfed treatment (0%). It was revealed that the drug/green herb ratio and spike stem length values formed three different groups in terms of irrigation levels. It was observed that, plant height was not affected neither by the methods nor by the irrigation levels since the averages of treatments showed similar values to each other, but it should also be noted that the gravimetric method and higher levels of irrigation water application resulted in greater plant height.

In the second experimental year, the results of variance analysis performed to determine the differences between yield and yield traits according to irrigation treatments are given in *Table 6*. As tabulated, the irrigation program methods and irrigation levels are strongly influenced all the traits investigated ($p < 0.01$), but the interactions of both factors were not significant.

Table 6. *Yield and yield components of lavender as influenced by irrigation program methods and irrigation levels (2021)*

		Green herb yield (kg ha^{-1})	**Drug herb yield (kg ha^{-1})**	**Drug/green herb ratio (%)**	**Plant height (cm)**	**Spike stem length (mm)**
Irrigation program method (M)	Pan	4787.5b	2300.8b	47.6b	56.8b	273.6b
	Gravimetric	5190.0a	2643.3a	50.5a	60.8a	294.8a
LSD $_{5\%}$		180.3	100.06	1.432	2.090	10.509
Irrigation Level (IL)	100%	5776.6a	3101.6a	53.7a	62.7a	320.3a
	67%	5473.3b	2748.3b	50.2b	60.0ab	297.7b
	33%	4905.0c	2323.3c	47.3c	58.2b	271.2c
	0%	3800.0d	1715.0d	45.0d	54.5c	247.5d
LSD $_{5\%}$		255.0	141.5	2.025	2.955	14.862
	M	**	**	**	**	**
	IL	**	**	**	**	**
	M x IL	ns	ns	ns	ns	ns

Means with different letters in the same column indicate significant differences between treatments according to LSD test (n = 3 replicates, $p < 0.05$)
**$p < 0.01$, ns: not significant

In line with the findings of 2020, the plots that were monitored using gravimetric method were produced the highest green herb (5190.0 kg ha^{-1}) and drug herb

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(2643.3 kg ha^{-1}) in 2021 and both yields were included in the first group. The yields obtained under pan method formed the second group. The plants responded to the irrigation levels in terms of yield, just as it was in 2020; full irrigated plots yielded the highest amounts of green herb yield (5776.6 kg ha^{-1}) and drug herb yield (3101.6 kg ha^{-1}) and the steady decrease was observed in yields with the reducing irrigation coefficients. Rainfed treatment gave the least green herb and drug herb yields with the averages of 3800.0 kg ha^{-1} and 1715.0 kg ha^{-1}. The rankings based on LSD test was in parallel with the findings of the previous experimental year; green and drug herb yields were included in four different groups. Unlike 2020, the drug/green herb ratio, plant height and spike stem length were significantly influenced by irrigation program methods and irrigation levels at $p < 0.01$ level in the second year of the trial, but the interaction of both factors found to be non-significant. For these traits examined, the averages of gravimetrically monitored plots exhibited higher drug/green herb ratio, plant height and spike stem length. Drug/green herb ratio and spike stem length fell into four different groups in the ranking, while plant height formed three groups. A similar tendency was observed in the traits investigated in terms of irrigation levels; the lesser the irrigation coefficient or the irrigation levels were, the smaller average data was measured from the plots.

Yield response factor of lavender (k_y)

The lavender yield response factor (k_y) was graphed for the 2-year data of the trial using Stewart's model (*Fig. 2*). The decrease in the relative green herb yield has linearly increased with the relative evapotranspiration deficit. The determination coefficient (R^2) was 0.88 for pan method and 0.76 for gravimetric method. The relationship was found to be significant at $p < 0.01$ for both methods and the yield response factor (k_y) of lavender was determined as 0.35 for pan method and 0.27 for gravimetric method.

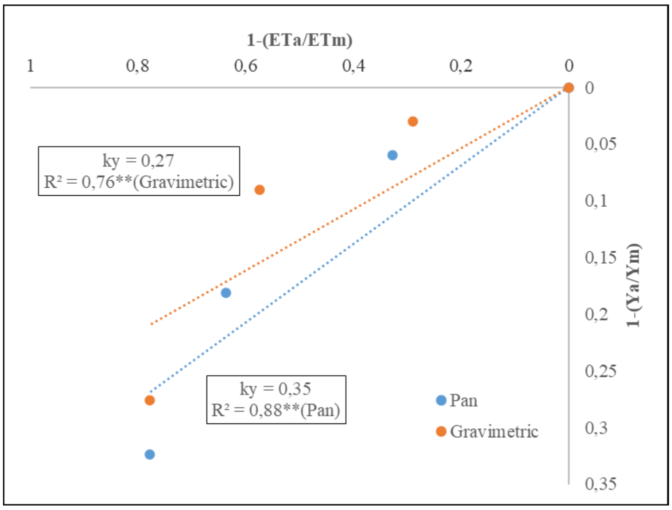

Figure 2. *Yield response factor (k_y) for lavender*

The relations between water use (ET) and green and drug herb yield

The relationship between water use-green herb yield and water use-drug herb yield were investigated and presented in *Figures 3* and *4* respectively. In the research years, both the irrigation program methods and irrigation levels had a significant effect

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($p < 0.01$) on green herb yield and drug herb yield and the interactions of the factors were not significant (*Tables 5* and *6*), therefore combined data of two experimental year were used in the evaluation.

The relation between water use and green herb yield under pan and gravimetric method was best described significant ($p < 0.01$) by second order polynomial equations with high determination coefficients R^2 (0.9834 for pan method and 0.9588 for gravimetric method) (*Fig. 3*).

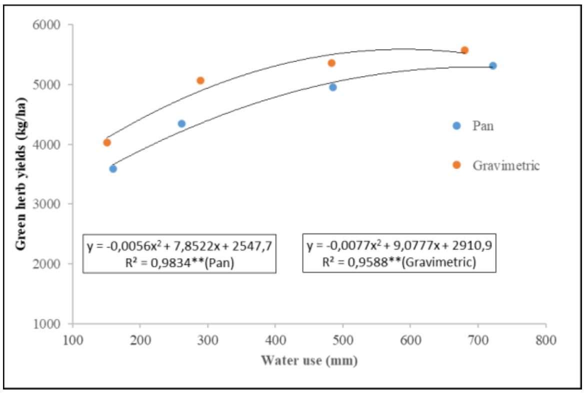

Figure 3. *Green herb yield as a function of water use*

Similar relationships was observed between water use-drug herb yield. Statistically significant ($p < 0.01$) second order polynomial relations were determined with high determination coefficients (R^2) for pan method as 0.9914 and 0.984 for gravimetric methods respectively (*Fig. 4*).

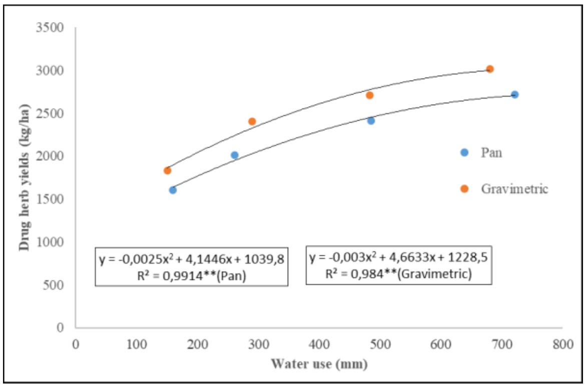

Figure 4. *Drug herb yield as a function of water use*

Discussion

The current study revealed that different irrigation program methods and varying irrigation levels had a significant impact on the yield, yield components, and yield-water relationships. Although deficit irrigation practices seemed to be promising for production, very limited studies were conducted to investigate the effects of the irrigation strategies on medicinal plant growth and development (Chrysargyris et al., 2016).

The fluctuation in the irrigation water amounts in trial years can be attributed to the total rainfall occurred above the long-term means in June in both trial years that

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maintained the soil moisture above the 50% level in the beginning of the irrigation period. The yield variation of deficit irrigated plots would be evident if the moisture of the soil profile reduces below the 60% of the available water (Sezen et al., 2011). Also, other meteorological factors play a substantial role in determining the water use of plants (Tarı et al., 2021). Noory (2020) applied 275 m^3 da^{-1} irrigation water to lavender grown in pots using seven different substrates. In the cultivation of *L. angustifolia*, the effect of supplementary irrigation was found to be useful (Sałata, 2020). Four different lavender species were irrigated at 100% easily available water (EAW) with 8.1 mm irrigation water day^{-1} and 4.05 mm day^{-1}, and the positive impact of providing plants with 100% EAW resulted in better crop development (Sałata et al., 2020). Changes in rainfall distribution due to climate change can affect the availability of water for irrigation. Irregular or reduced rainfall can result in insufficient water for lavender plants, leading to decreased productivity and potential loss of crops. Therefore, supplying irrigation water will foster the growth and higher yield of lavender plants.

In this study, gravimetrically monitored and irrigated plots received less irrigation water than the plots irrigated under pan method. This difference could be attributed to the data collection methods used by these two approaches. Pan method is indirectly dependent upon the climatic variables effecting evaporation, while gravimetric method is a direct measuring method of soil water content. The availability of the irrigation system and the objectives of the grower largely determine the choice of irrigation method (Jones, 2004). Achieving higher yields with better quality would only be possible by proper irrigation scheduling (Lovelli, 2007). By implementing a proper irrigation schedule, the timing and amount of water applied for irrigation are determined. However, due to the challenges associated with sampling and measuring soil moisture, the pan evaporation method is a more convenient and practical choice for farmers when it comes to irrigation scheduling (Ashraf et al., 2002). Although the gravimetric method is a time and labor consuming method in soil moisture monitoring (Little et al., 1998), it is the fundamental method in measuring soil moisture, as used in the calibration of most of the soil moisture monitoring methods. Regular monitoring of weather patterns and soil moisture levels can help farmers adapt their irrigation practices based on changing conditions.

The crop evapotranspiration increased with the increments in irrigation levels and differentiated according to irrigation program methods. In the study, the lowest crop ET values were obtained from the rainfed treatments (P_4 and G_4) and the highest water consumption values were obtained from P_1 and G_1 treatments in which full irrigation water was applied during the growing season. In this study, the crop evapotranspiration varied between 144.0-739 mm according to treatments. Although there is lack of literature reported on the crop ET of lavender, Noorollahi et al. (2016), determined the water use of *L. angustifolia* as 1191.4 mm in a lysimeter experiment in Iran. In the same research, daily ET_{min} and ET_{max} of lavender were measured as 7.82 mm day^{-1} in June and 0.62 mm day^{-1} in January, respectively. The crop ET of basil under full irrigation was determined as 431 mm while it was 270 mm in rainfed conditions (Pejic et al., 2017). The highest and lowest ET was determined to be between 34.3-349.0 mm in basil plants under different vermicompost doses (Şenyiğit et al., 2021). Ghamarnia et al. (2015) determined the ET of basil in lysimeters between 636.8-849 mm. The variations in ecological conditions could describe the distinction between the current study and the results of these studies.

The amount of the yield or biomass harvested against each unit of water consumed by the plant is expressed as water use efficiency (WUE), while irrigation water use

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efficiency (IWUE) is calculated for a unit of irrigation water applied to the plant. In the study, WUE and IWUE values were calculated higher in the plots which received less water and irrigated by gravimetric method. This exhibits the behaviour of the crop using unit water in a more efficient manner as the irrigation level decreases. The IWUE values were relatively higher than WUE values which is an indication of the water use from the soil profile storage. The IWUE results of this research coincide with the study conducted on purple basil by Ekren et al. (2012). Şenyiğit et al. (2021) determined the highest WUE as 447 kg da^{-1} mm^{-1} from 75% irrigation level in basil, while the lowest was obtained from rainfed treatment as 115 kg da^{-1} mm^{-1}, the highest IWUE was also determined under 75% irrigation level as 432 kg da^{-1} mm^{-1}. Pejic et al. (2017), determined the WUE of basil as 1.65 kg m^{-3} and IWUE as 1.89 kg m^{-3}. Available water in the soil profile and water use efficiency determines the plant productivity (Xu and Hsiao, 2004). The findings of the study in terms of WUE and IWUE shows the sensitivity of the green herb yield of lavender to soil moisture.

The highest green herb yields were harvested from the fully irrigated treatments of both methods in which the highest water use was occurred and the vegetative growth was fostered by irrigation. The yields of the plants are depending on temperature, irrigation, fertilization, plant number and the genotype (Ekren et al., 2012). In this study, the green herb yields of the full irrigated treatments were found to be higher than the results of Arabacı and Bayram (2005), Baydar and Erbaş (2007) and Atalay (2008), but Kara (2011) and Karık et al. (2017) observed higher green herb yields. The increase in irrigation levels significantly improved the average drug herb yields. The green herb yield of lavender plants that were supplementally irrigated had higher yields at 0.68 kg m^{-2} compared to the crops without supplemental irrigation (Sałata, 2020). Irrigation level in 75% of field capacity resulted in highest herb yield in basil (Khalid, 2006). In parallel with the findings of the green herb yields, the results of this research showed a similar tendency to the literature mentioned above. The decrease in soil moisture may induce a reduction in photosynthesis and, as a consequence, a reduction in plant growth (Tabatabaei et al., 2012).

In the evaluation of drug/green herb ratio, spike stem length, and plant height, differences were observed between irrigation program methods and irrigation levels in both years. Higher values were obtained from plots that were gravimetrically monitored and fully irrigated. Various environmental factors, particularly water stress, are influencing the growth of aromatic plants (Burbott and Loomis, 1969). Drought significantly reduces morphological features such as leaf area, number of leaves per plant, specific leaf area, leaf weight ratio, leaf area ratio, and leaf dry weight in lavender plants (Nogues and Baker, 2000) Additionally, an observed decrease in plant height, stem diameter, leaf length, and fresh biomass of lavender is associated with increasing water deficit (Chrysargyris et al., 2016). Water deficit had a negative effect on the plant height of purple basil (Ekren et al., 2012). In this study, the plant height of the fully irrigated treatments was consistent with the findings of previous research conducted by Arabacı and Bayram (2005), Baydar and Erbaş (2007), Atalay (2008) and Kara (2011).

The yield response factor (k_y) is determined by the correlation between relative crop evapotranspiration and relative yield decrease. The k_y value obtained is less than 1, indicating that the crop is less sensitive to a reduction in unit water. Under deficit irrigation conditions prevailing during the growing season, crops with smaller k_y can tolerate water deficiency better than crops with higher k_y (Doorenbos and Kassam, 1979). Şenyiğit et al. (2021) determined the k_y for basil as 1.18, while Pejic et al. (2017)

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determined it as 0.22. In this study, the k_y of the lavender was determined as 0.27 in gravimetrically scheduled plots and 0.35 using the pan method. So, it can be concluded that lavender has good adaptation skills to deficit irrigation regimes and irrigation scheduling by the gravimetric method would help the plant survive itself under water scarcity.

The second-order polynomial correlations between ET-green herb yield and ET-drug herb yield indicate that the yields were adversely influenced by irrigation levels under different irrigation scheduling methods. This shows that as the ET increases to a certain level, both green and drug herb yields also increase, but then decrease slightly.

Conclusion

Climate change can have a significant impact on lavender plantations and their irrigation practices, resulting in increased water stress and potential challenges for lavender cultivation. In arid and semi-arid regions, water scarcity is a significant abiotic stress factor that diminishes plant productivity and growth.

Meeting the water requirements of lavender during the growing season has an important effect on increasing the green herb yield. In the event that a constraint needs to be imposed on the water source, it is preferable to consider the treatment options that provide 33% water savings (P_2 and G_2) using the gravimetric and pan methods, while taking into account the values of WUE and IWUE. However, in terms of yield and yield components, it was determined that the most appropriate irrigation program was the G_1 treatment, which received full irrigation water and monitored by the gravimetric method. This situation revealed that lavender green herb yield varies depending on the water level applied and the chosen irrigation scheduling method.

Climate change can alter precipitation patterns and lead to more frequent and prolonged droughts, causing water stress for lavender plants. Lavender requires consistent moisture, especially during its early growth stages. Water scarcity can impact the quality and yield of lavender crops. Implementing efficient irrigation techniques, such as drip irrigation, can help conserve water and ensure that lavender plants receive adequate moisture without excessive water usage.

In the context of a changing climate, it is important to develop drought mitigation and adaptation strategies for lavender cultivation. Improved irrigation techniques, water conservation practices, climate-resilient varieties, microclimate management, monitoring, and adaptation are the main themes to be considered.

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