Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2024, 11(11):30-37

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

The Effect of Different Irrigation Water Levels on Yield and Yield Characteristics of Thyme (*Thymus vulgaris* l.) in Aydin Province

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Abstract: This study was conducted in 2023 under Aydın Plain conditions to determine the effects of deficit irrigation on water-yield relationships in thyme plants. The Class A Pan evaporation method was used in irrigation programming. In the study, four different irrigation levels (100%, 67%, 33%, and rainfed (0%)) subjects were applied in three replications. Seasonal plant water consumption varied between 142 and 333 mm according to irrigation programs. Green herb yield was found between 486 – 1084 kg/da. Average water use efficiency (WUE) values varied between 3.26-4.76 kg/m^3. While the water resource is not limited, it can be said that the best irrigation subject is I_{100}, in which the irrigation program has been determined according to the Class A Pan evaporation method and the irrigation water is fully applied. When it comes to the necessity of applying a constraint on the water source, the applicability of the subjects that provide 67% water savings (I_{67}) in the evaporation method has emerged.

Keywords: Aydın, thyme, drip irrigation, yield response factor.

1. Introduction

Thyme (*Thymus vulgaris* L.) is an important medicinal plant in perfume and medical industry. The thyme is among the most distinguished raw material for pharmaceutical and cosmetic industry. The rising demand to thyme in industry necessitates the investigations on achieving more yield per area by using less water, in such a world that drought becoming a threat day by day. Water deficit stress, permanent or temporary, limits the growth and the distribution of natural vegetation and the performance of cultivated plants more than any other environmental factors. Water scarcity and drought are the major factors constraining agricultural crop production in arid and semi-arid zones of the world. Irrigation is today the primary consumer of fresh water on earth and thus agriculture has the greatest potential for solving the problem of global water scarcity [1]. Consequently, improvements in management of agricultural water continue to be called for to conserve water, energy and soil while satisfying society's increasing demand for crops for food and fiber [2].

The production under cultivation of most of the medicinal and aromatic plants in Turkey was quite limited until the early 2000's and the requirement has been met by collecting from the nature. In recent years, with the rising interest of most of the people towards medicinal and aromatic plants, the cultivation, use and trade has been on the rise by state supported growing projects and the total cultivated area reached to 4 718 ha with a total production of 7 722 tonnes in Turkey [3,4].

Climate change can significantly impact thyme plantations and their irrigation practices, leading to increased water stress and potential challenges for thyme cultivation. Although medicinal and aromatic plant growth is supported by the government in recent years in Turkey, the consequences of climate change brings several problems for growers; drought, more frequent heat waves and water deficit. Drought stress should be considered as a threat to the development and yield of the plants [5], therefore strategies should be developed to avoid its effects. Even though the thyme plants have ability to survive in rainfed conditions, the cultivated thyme varieties are mostly irrigated with surface irrigation methods. Water shortage, increasing production cost and low water use efficiency (WUE) made the economical profit marginal and challenging to the end users. Thus new irrigation strategies must be established to use the limited water resource more efficiently. One of the new irrigation strategies is the deficit irrigation scheduling, which is a valuable and sustainable production strategy for dry regions [6]. In other words, conventional deficit irrigation is one approach that can reduce water use without causing significant yield reduction [7]. However, the use of drip irrigation techniques is inevitable in the near feature because of the salinity problem caused by traditional irrigation methods [8]. Also, drip irrigation have been suggested as a means of supplying most types of crops with frequent and uniform applications of water, adaptable over a wide range of topographic and soil conditions [9]. Under good management practices, deficit irrigation can result in substantial water savings with little impact on the quality and quantity of the harvested yield. Since the thyme branches are sensitive to water-induced diseases, drip irrigation method is recommended for healthy crop growth [10].

Common irrigation methods used for thyme production are wild flooding, basin strip and furrow surface irrigation methods. Water application alters the yield and essential oil content in several aromatic plants [11]. Under fully irrigated conditions, yield of fresh and air dried lavender leaves and essential oil content were increased [12]. The water use of *Lavandula angustifolia Mill.* was determined as 1191.4 mm in lysimeters by using water balance approach [13]. As the water supply increases, an increase was observed in the drug herb yield and leaf yield of oregano [14]. Different irrigation water levels influenced the green herb yield, drug herb yield, drug leaf yield and plant height of purple basil [15]. Deficit irrigation reduced seed yield, biological yield and water use significantly, but water use efficiency (WUE) was significantly increased in Isabgol and French psyllium [16]. Decreasing irrigation intervals increased the biomass and yield of *Plectranthus amboinicus* plants [17]. The yield, main stem length and main stem weight of dill plants exposed to three different irrigation levels showed a significant change [18].

In recent years, drip irrigation has gained popularity among thyme producers due to incentives provided by the government. In general, the farmers over irrigate, resulting in high water losses and low irrigation efficiencies, thus creating drainage and salinity problems [19]. The dependence of crop yields on water supply is a critical issue due to the increasingly limited water resources for irrigation in the Aegean region and its semi-arid climate of western Turkey. However, little attempt has been made to assess together deficit irrigation and drip irrigation techniques for thyme in the Aegean region. Few research have reported the effects of irrigation on the yield and quality of thyme, but there is a lack of information about the yield-water relationships, yield response factor (ky) and water consumption of the plant. Therefore, it was aimed to determine the crop water requirement and its relations with yield and yield components of Thyme (*Thymus vulgaris* L.) under different drip irrigation strategies.

2. Materials and Methods

This study were conducted during the growing seasons of 2023 at the Agricultural Research Station of Aydın Adnan Menderes University, Aydin-Turkey at 37° 51' N latitude, 27°51' E longitude. Mediterranean climate prevails in the region with dry and hot summers and rainy, warm winters. There was no waterlogging problem and the average annual rainfall was 644.7 mm with a mean monthly temperature of 17.8 ^{o}C according to long-term meteorological data (1983-2022) in the experimental area.

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%-23.1% and 7.3%-10.1%. in 0-90 cm soil depth respectively. Total available water capacity is 162 mm/0.9 m.

Thyme (*Thymus vulgaris* L.) variety was planted on 27 March 2023, with 1.00 × 0.20 m spacing. Supplemental irrigation was applied to the whole experiment at the transplanting at 40 mm. Before transplantation of the seedlings, 40 kg ha^{-1} $(NH4)_2SO_4$ fertilizer was applied to the trial area. Also liquid fertilizer was applied two times by foliar spraying in order to supply microelement requirement of the plants. Weed control and hoeing was made by hand regularly during the growing season.

The trial was designated in randomized complete block design with three replications. In the study, Class-A Pan evaporation (Pan) method was used in drip irrigation programming. Four irrigation levels (rainfed treatment (I_0), (100% as well as fully irrigated treatment and 33% and 67% times of the full irrigation treatment) were used.

I_{100} treatment received the total sum of 100% of the pan evaporation occurred in 7-day interval and I_{67} and I_{33} received 67% and 33% of it respectively.
Equation (1) was used to calculate the irrigation water amount for applications;

$$V = P \times A \times E_{pan} \times WL \qquad (1)$$

Where V is the volume of irrigation water (L), P wetting percentage (taken as 100 % for row crops), A is plot area (m^2), E_{pan} is the amount of cumulative evaporation during a 7-day irrigation interval (mm), WL represents irrigation levels (0.33, 0.67 and 1.00).
Drip laterals were placed at the center of adjacent crop rows 0.70 m apart in the experimental plots. Experimental plots were 5 m long and 5 crop rows wide (3.5 m). Irrigation water was used from a deep well located near the experimental site. The control unit consisted of screen filter with 10 L/s capacity, control valves, manometers mounted on the inlet and outlet of each unit. Distribution lines consisted of PVC pipe manifolds for each plot. The diameters of the laterals were 16 mm PE and each lateral irrigated one plant row. The inline emitters were used with a discharge rate of 4 L/h above 10 m operating pressure. In the system, emitter and the lateral spacing were chosen as 0.20 and 0.70 m, respectively (Fig. 1).

Figure 1: Application of drip irrigation plot

Crop water consumption under varying irrigation regimes was calculated using the soil water balance equation [20] as;

$$ET = R + I - D \pm \Delta W \qquad (2)$$

Where, ET is the water use (mm), *R* is the rainfall (mm), *I* is the depth of irrigation (mm), *D* is the depth of drainage (mm), and ΔW is the change of soil water storage in the measured soil depth.
WUE was calculated as yield (kg/da) divided by seasonal water use (mm). IWUE was determined as yield (kg da) per unit irrigation water applied (mm) [21]. Regression analysis was used to evaluate the water use-yield relationships derived from seasonal crop water use and yield data obtained from the experiment. Seasonal values of the yield response factor (k_y), which represent the relationship between relative yield reduction [1-(*Ya*/*Ym*)] and relative evapotranspiration deficit [1-(*ETa*/*ETm*)], were determined using equation 3 given by Doorenbos and Kassam [22]:

$$1-(Ya/Ym)=k_y(1-ETa/ETm) \qquad (3)$$

Where, *ETa* and *ETm* are the actual and maximum seasonal crop water use values (mm), respectively, and *Ya* and *Ym* are the corresponding actual and maximum yields (kg/da).

Harvesting and sampling was made on 12 July 2023. In trial year, the plants were harvested and plant height (cm) was measured in the harvest. Green herb yield (kg/da) and drug herb yield (kg/da) were determined separately for each plot. In order to determine the differences between irrigation treatments, the data relating to yields were subjected to variance analysis. The Least Significant Differences (LSD) test was used for comparing and ranking the treatments. Differences were declared significant at $p < 0.05$. Variance analysis and LSD tests were carried out with the use of the TARİST program, which was developed for this purpose [23].

3. Results & Discussion

Irrigation water amounts (I), seasonal evapotranspiration (ET), green herb yield and water use efficiency values (WUE, IWUE) for thyme plant in experimental year were presented in Table 1. Altogether 10 treatment irrigations varying from 93 to 280 mm in I_{100} plots were practiced. The first irrigation was applied on May 2 and irrigations were lasted on July 4, in 2023, respectively.

Table 1: Seasonal irrigation water, water use, average green and drog herb yield, WUE and IWUE data for different treatments

Irrigation Treatment	Seasonal Irrigation Water (mm)	Seasonal Water Use (mm)	Average Green Herb Yield (kg/da)	Average Drug Herb Yield (kg/da)	Plant Height (cm)	Water Use Efficiency (WUE) (kg/m^3)	Irrigation Water Use Efficiency (IWUE) (kg/m^3)
I_{100}	280	333	1084.0a	456.3a	23.9a	3.26	3.87
I_{67}	188	228	888.0b	397.6b	22.4b	3.89	4.72
I_{33}	93	153	728.3c	355.3c	21.1c	4.76	7.82
I_0	-	142	486.3d	242.6d	17.0d	3.42	-
P<0.01			**	**	**		
LSD%5			70.926	37.701	0.739		

*P< 0.05; **P< 0.01; ns: not significant

In a column values with a common letter are not significantly differ from one another using LSD%5

Seasonal plant water use values varied in connection with the irrigation water applied to the treatments and the amount of moisture at planting and harvest. Plant water use was higher at full irrigation level (I_{100}) than in the deficit irrigation plots. Water use values increased with increasing irrigation levels in each irrigation approaches. Seasonal water use varied from 142 to 333 mm among the different treatments. The highest water use was observed in I_{100} treatment as 333 mm, and the lowest water use was measured in I_0 rainfed treatment as 133 mm. This was followed by I_{33} and I_{67} treatments, 153 and 228 mm in the growing season, respectively (Table 1). Although there is lack of literature reported on the crop ET of thyme, [13], 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 was measured as 7.82 mm day^{-1} in June and 0.62 mm day^{-1} in January, respectively. In basil in full irrigation conditions crop ET was determined as 431 mm while it was 270 mm in rainfed conditions[24]. Highest and lowest ET was determined between 34.3-349.0 mm in basil plants under different vermicompost irrigation levels[25]. [26] determined the ET of basil in lysimeters between 636.8-849 mm. The variations in ecological conditions could describe the gap between the results of these studies.

Green herb yields varied from 486 to 1084 kg/da among the treatments (Table 1). The highest average green herb yield was observed in I_{100} treatment as 1084 kg/da and the lowest yields were found in I_0 treatment as 486 kg/da. The average of highest drug herb yield I_{100} plots was 456 kg/da. The averages of the plots in which the crop water requirement was fully met gave the highest drug herb yields. This was followed by 67% irrigation level with an average yield of 397 kg/da. The lowest drug herb yield was harvested from the rainfed plots. On the other hand, the response of green herb and drug herb yield to different irrigation treatments (variance analyze) are given in Table 1. Data obtained from study showed that green and drug herb yields were significantly affected by irrigation levels ($p< 0.01$). Green and drug herb yields were found to increase with irrigation water levels. Examining these results from the point of view of irrigation levels (IL), four groups formed in year. The first group consisted of the 100% treatments where no water restriction had been applied in the whole growing season, treatments in which water had been applied at the 67 % level were second, and treatments which had received water at the 33 % level formed the third group. Especially, as the irrigation level increased, green and drug herb yields were increased in all applications. The yields of the plants are depending on temperature, irrigation, fertilization, plant number and the genotype [15]. In this study, the green herb yields of the full irrigated treatments were found to be higher than the results of [27, 28, 29], but [30, 31] observed higher green herb yields. The increments in the irrigation level remarkably increased the average drug herb yields. The green herb yield of supplementally irrigated lavender plants had higher yields as 0.68 $kg{\cdot}m^{-2}$ than the crops without supplemental irrigation [32]. Irrigation level in 75% of field capacity resulted in highest herb yield in basil [33].

As the amount of water applied increased, WUE and IWUE decreased. In general, the IWUE values were higher than those of WUE in all treatments. This could be attributed to water used from soil storage. The highest water use efficiency (WUE) averaging 4.76 kg/m^3 was obtained in I_{33}, followed by I_{67} with 3.89 kg/m^3 and the lowest one was found in the I_{100} treatment as 3.26 kg/m^3 (Table 1). Treatment I_{33} from all applications used to water more efficiently. [25] determined the highest WUE as 447 kg/da/mm from 75% irrigation level in basil, while the lowest was obtained from rainfed treatment as 115 kg/da/mm, the highest IWUE was also determined under 75% irrigation level as 432 kg/da/mm. [24], 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 [34]. The findings of the study in terms of WUE and IWUE shows the sensitivity of the green herb yield of thyme to soil moisture. On the other hand, in our study both WUE and IWUE values were similar to the findings of other researchers [15, 35, 36].

In order to evaluate the effects of water use on green and drog herb yields regression analysis was conducted. There was a significant second order polynomial relationships were found between seasonal water use and green-drug herb yield in irrigation treatments (Fig 2). Polynomial relationships of water use and yields for drip irrigated medicinal and aromatic plants were given by [25, 36].

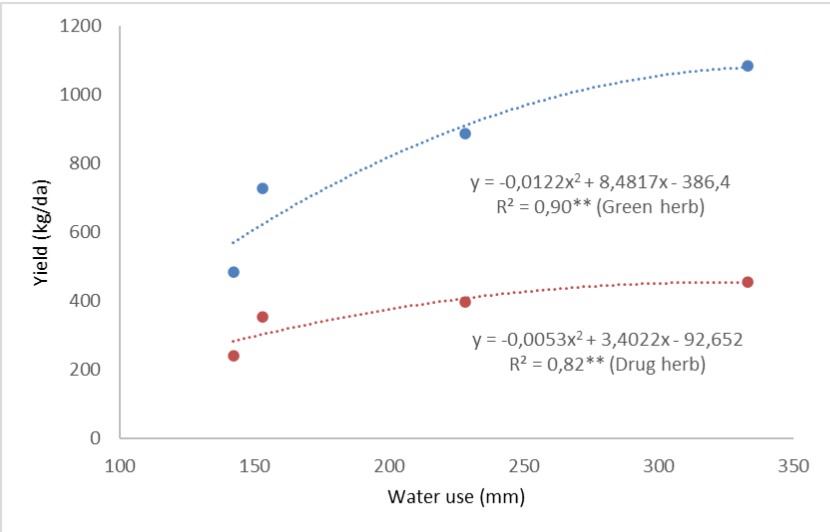

Figure 2: The relationship between plant water use and green-drug herb yields

The k_y factor which represents the slope of the relationship between relative ET and relative yield, was determined the methods of [22]. Yield response factor (k_y) was found to be 0.76 for traditional deficit drip applications (Fig. 3). The average k_y for the whole growing season were found to be 0.31 by [36], 1.18 by [25].

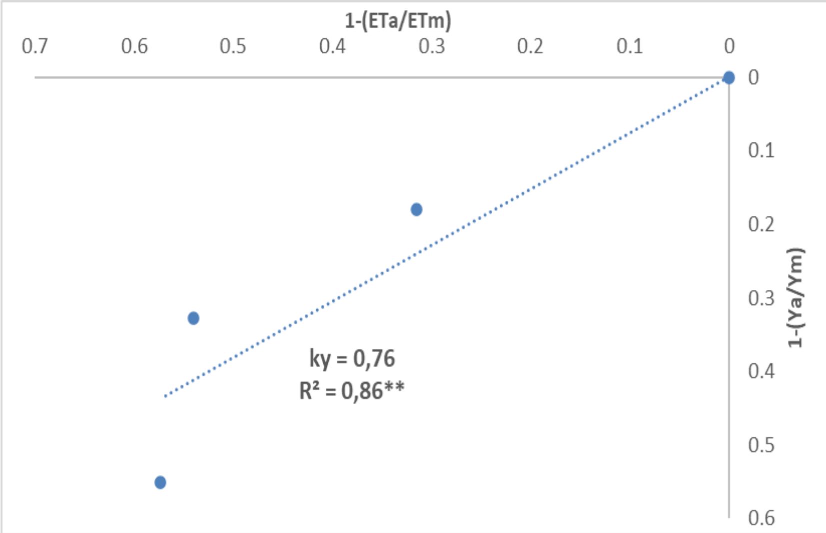

Figure 3: Yield response factor (ky) of thyme for different irrigation treatments

4. Conclusion

In this study, we evaluated the effects of different irrigation water levels on yields and water use efficiency of the drip irrigated thyme plant under Aegean semi-arid climatic conditions in western Turkey in 2023. Meeting the water requirement of thyme plant during the growing season has an important effect on increasing the green herb yield. Overall, the results of this research indicated that drip irrigation applications, with I100 treatment could be used for thyme grown in Aegean region similar to the area in Turkey under no water shortage. In case of the necessity for applying a constraint in the water source arises, the treatment that provide 67% water savings (I33) under drip irrigated plots. Therefore, results obtained from the drip irrigation applications, I33 treatment could be used as a good basis for reduced drip irrigation strategy development in semi-arid regions under water shortage.

Acknowledgment

This research was funded by Aydın Adnan Menderes University Scientific Projects Coordinaton Unit. (Project No: ZRF-23007). This study was conducted as Gamze AKKURT's Master Thesis project and summarized from her thesis.

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