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Deficit Irrigation Effects on Rosemary Plant (*Rosmarinus officinalis* L.) Parameters in a Semi-arid Climate

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ABSTRACT

Deficit Irrigation is one of the ways to use water resources efficiently. In this method, a part of the plant's water requirement is eliminated so that it does not have significant effects on its yield. In this study, between 2017 and 2018, the effects of deficit irrigation on rosemary plant was investigated. The research site was the research station of the Water Engineering Department of the Campus of Agriculture and Natural Resources of Razi University in Kermanshah, by using the available Lysimeter Two-factor factorial based on a completely randomized design with four treatments (100, 75, 50 and 25% of water requirement) and three replications were applied. The results showed that irrigation treatments of 75% and 50% of plant water requirement had the same performance in producing essential oil at the rate of 0.3 cm^3/plant. However, the highest amount of essential oil production with a value of 0.4 cm^3/plant was observed in full irrigation treatment. From the obtained results, it can be concluded that increasing the level of deficit irrigation significantly affected the Rosemary components such as root depth, essential oil, dry matter, and reduced all indicators (except the number of branches) compared to the control treatment. Finally, due to the reduction of all plant parameters, the amount of essential oil and dry matter yield due to increasing the level of water deficit, irrigation of rosemary with a deficit irrigation level of 50% does not seem reasonable and cannot be recommended. But at the 75% level, this reduction in performance can be considered acceptable and based on results in the case of rosemary cultivation to produce dry matter, irrigation at the rate of 75% of the plant requirement is sufficient, but in the case of rosemary cultivation to produce essential oil, the plant's water requirement should be fully met.

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1. Introduction

Rosemary (*Rosmarinus officinalis*) is a perennial plant that is of special importance in Iran due to its wide use in the pharmaceutical and health industries. It is native to the Mediterranean coast, and in Iran, Tehran province has the highest area under cultivation of this plant in the country (Fazeli-Nasab *et al.*, 2021).

Drought stresses and water constraints are one of the most important factors limiting the production of agricultural products and the occurrence of these water stresses disrupts the growth and development stages of the plant (Eskandari and Kazemi, 2019). Therefore, to compensate for this issue and increase water productivity, various methods, including the use of deficit irrigation management methods have been proposed by researchers.

Deficit irrigation is also a type of irrigation management during which the plant tolerates a certain degree of drought stress. In a way that with better use of each irrigation unit, better crop yield is obtained and by performing proper management in the water, soil and plant system, sustainable agriculture can be created while producing the crop optimally (Fadul *et al.*, 2020; Xu *et al.*, 2019).

Researchers have stated that water stress in rosemary, in addition to saving the amount and increasing water productivity, caused a significant increase in plant growth and at low levels of stress, the amount of oil and essential oil was increased (Walters *et*

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al., 2016; Swamy *et al*., 2008). In order to investigate the effects of drought and salinity stress on rosemary, an experimental design was conducted the results showed that the use of environmental stresses with an effect on the growth parameters of the production of secondary metabolites and phenolic content increased the yield of rosemary (Dehghani Bidgholi, 2018).

In a study, four levels of irrigation (100, 85, 70 and 55%) were applied to rosemary and the results showed that T85 saved 348 M^3 of water and increased water use efficiency by 11.3% compared to T100 (Rigi Karvandri *et al.*, 2020) . Evaluation of rosemary under different water stresses has shown significant positive effects on the quantity and quality of the resulting (Sarmoum *et al.*, 2019). Researchers studying the effect of dehydration on the mint plant said that dehydration reduces plant growth, but on the other hand increases factors such as antioxidant capacity and the amount of phenols as well as plant pigments (Chrysargyris *et al.*, 2021). Based on the results of another research on the study of the role of bio-fertilizers in improving the productivity of rosemary plant in water shortage conditions, irrigation composition at the rate of 800 m3/fed and the use of PGPR show the highest values of essential oil percentage (Hammam *et al.*, 2021). In a study, drought stress was applied in the area of mint root and the results showed that by applying water stress at a level of 70% of the plant's water requirement, the maximum amount of essential oil yield can be achieved (Akbarzadeh *et al.*, 2022).

Because the cultivation of medicinal plants, including rosemary, has become common in all parts of Kermanshah province, therefore, the present study was conducted during two cropping seasons to investigate the effects of deficit irrigation on all plant parameters and rosemary essential oil as one of the most valuable medicinal plants in a semi-arid climate. Hope, it would be a good guide for water management of this valuable medicinal plant in all around the country and in different parts of the province with the problem of water shortage and semi-arid climate.

2. Materials and methods

This research was conducted during the two crop years of 2017 and 2018 in the research farm of Razi University, Faculty of Agriculture and Natural Resources, which is located at a longitude of 47° 9' east and latitude of 34° 21' north and altitude 1319 meters above sea level. This region has a semi-arid climate.

During the research, meteorological data were received daily from a fully automatic meteorological station located fifty meters from the test site. Meteorological parameters during the growth period of the rosemary plant, physical and chemical soil and water characteristics during the experimental period in 2017 and 2018 are presented in Tables 1 to 4, respectively.

Table 1. Average meteorological parameters in the first and second year of project implementation.

Year	Month	Average temperature (C)°	Average relative humidity (%)	Average wind speed (m/s)	Average hours of sunshine (hr)	Monthly rainfall (mm)	Radiation (j/cm^2)
2017	June	24.9	21.4	7.9	9.7	0	2546.5
	July	28.1	19.6	7.6	10.2	0	2574.2
	August	29.8	16.3	7.8	9.9	0	2575.3
	September	25.9	14.6	7.4	10.3	0	1777.0
2018	June	23.3	27.4	7.4	9.2	0	2555.6
	July	29.1	14.7	7.4	11.6	0	2564.1
	August	27.6	18.4	7.3	10.1	0	2565.3
	September	23.2	15.4	7.6	9.1	0	1767.2

Table 2. Physical characteristics of the soil of the study area (Laboratories of "Water Engineering" Department, Agriculture and Natural Resources Campus, Razi University).

Sampling depth (cm)	Bulk Density (g/cm^3)	soil texture	Sand%	Silt%	Clay%
30-0 60-30 90-60	1.3	Silty- clay	3.7	42.3	54

Table 3. Chemical characteristics of soil in the study area (Laboratories of "Water Engineering" Department, Agriculture and Natural Resources Campus, Razi University).

Cu (mg/kg)	Zn (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Oc(%)	K (ppm)	P (ppm)	EC (µmohs/cm)	PH
1.64	1.36	11.9	7.8	1.38	440	26	0.60	7.3

Table 4. Physical and chemical properties of water (Laboratories of "Water Engineering" Department, Agriculture and Natural Resources Campus, Razi University).

TDS (mg/lit)	PH	EC (µmohs/cm)	SAR(%)	Na^+	$Mg^{+2}Ca^{+2}$	SO_4 (meq/lit)	Cl^-	Hco_3^-	Co_3^{-2}
640	7.1	1000	0.54	1.08	8.15	1.18	1.9	6.15	0.0

Rosemary was planted in June every two years by transferring the plants to the planting site. The growth period of the plant was 125 days and the plant continued to grow until flowering and suitable conditions for obtaining essential oils from the plant. It should be noted that after a 125-day growth period, the plants were removed from the soil and a new plant was planted again the following year. Sampling began with the beginning of the growing season. To obtain the amount of plant water requirement, evaporation data from the pan were received daily from the meteorological station located fifty meters from the station. In this study, class A evaporation pan and (Eq.1) and (Eq.2) were used to determine the potential and actual evaporation rate.

$$ETO = Kp \times E_{pan} \quad (1)$$

In this equation, ETo is the potential evapotranspiration, Kp is the coefficient of the pan, and E_{pan} is the evaporation rate from the measured pan (mm). The values of evaporation pan (Kp) were considered equal to 0.7.

$$ETc = Kc \times ETo \quad (2)$$

In this equation, Kc is the plant coefficient and ETc is the actual plant evapotranspiration (mm). In equation 2, Kc values for the initial, developmental, middle and final stages of plant growth were considered 0.30, 0.63, 1.04 and 0.96, respectively (Ghamarnia *et al*., 2014). Irrigation regime treatments were: 25%, 50%, 75% and 100% of plant water requirements. The experiment was performed in three replications and a total of 12 lysimeters with an outer diameter of 50 cm. To determine the yield of total dry matter weight, 5 plants were selected from each lysimeter and the parameters of plant height, number of branches per plant and dry weight were measured. To prevent wastage of essential oils, the plants harvested in the shade were dried in the laboratory. In this study, the Soxhlet method was used to obtain essential oils. (Nourian Sarvar, 2010).

3. Results and discussion

Table 5 represents the cumulative water consumption of the cultivation months. The lowest water requirement of the plant during the two years of research in June was 28 and 24 mm and the average was 26 mm during the two years of testing, respectively. The highest water consumption of the plant in September was 171 and 166 mm and the average was 169 mm, respectively. The average water consumption of the plant during the two years of cultivation was 486 mm.

Table 5. Water requirement of rosemary during the growing months.

Year \ Month	June	July	August	September	October	Total water requirement (mm)
2017	28	70	156	171	73	498
2018	24	67	149	166	67	473
Average	26	68	153	169	70	486

3.1. Performance components

All the main parameters of rosemary were measured at the end of the growing season and analyzed by Duncan's test, the results of which are presented in Table 6. This study investigated the effect of different levels of deficit irrigation at the probability level ($P < 0.01$) on the main morphological characteristics of the plant including root depth, number of branches, plant dry weight, plant fresh weight, plant height and essential oil. Mean comparison of data showed that the effect of different irrigation treatments on root depth at the level of 1% was significant. Therefore, according to the results, it can be acknowledged that the complete supply of soil moisture deficiency has played an important role in the root depth parameter so that the highest amount of this parameter has been observed in the treatment of 100% water requirement of 36.8 cm and the lowest average root depth with 11.2 cm was observed in the treatment of 25% water requirement. According to Table 6, the results show that reducing the amount of irrigation water did not have a significant effect on the number of branches per plant. Instead, the dry weight of the rosemary plant was significantly affected and the highest average of the mentioned parameter occurred in full irrigation treatment and the lowest average occurred in 25% irrigation treatment with the amount of 36.6 and 16.7 g, respectively. Also, based on the results, reducing the amount of irrigation water had a significant effect on the average fresh weight of the plant. The average fresh weight of the plant for 100% and 25% irrigation was 53.8 and 29.9 g, respectively. Plant height was also been significantly affected by deficit irrigation. The maximum average plant height obtained in 100% and 25% irrigation is 40 and 14 cm, respectively.

One of the most important parameters studied in this research was the parameter of the amount of essential oil and the effects of deficit irrigation on it. Based on the results obtained in Table 6, the effects of deficit irrigation on the amount of essential oil were significant, and the average of this parameter was 0.4 cc/20g in full irrigation and 0.2 cc/20g in 25% irrigation.

Table 6. The effect of different treatments on plant parameters.

Year	Consuming water (mm)	Irrigation Levels (%)	Treatment	Esential oil (cc/20g)	Plant height (cm)	Fresh plant weight (g)	Dry plant weight (g)	Number of branches per plant	Root depth (cm)
2017	498	100	A1	0.4^{a}	36^{a}	50.3^{a}	33.3^{a}	21^{a}	34.0^{a}
	373	75	A2	0.3^{ab}	33^{a}	41.7^{ab}	29.4^{ab}	16^{a}	32.7^{a}
	249	50	A3	0.3^{ab}	20^{b}	30.2^{ab}	13.6^{b}	14^{a}	16.3^{b}
	125	25	A4	0.2^{b}	16^{b}	24.8^{b}	14.6^{b}	13^{a}	11.7^{b}
2018	473	100	A1	0.5^{a}	43^{a}	57.3^{a}	39.8^{a}	26^{a}	39.7^{a}
	355	75	A2	0.3^{a}	41^{a}	50.3^{a}	35.6^{a}	22^{a}	39.3^{a}
	237	50	A3	0.3^{a}	17^{b}	33.7^{a}	18.7^{b}	17^{a}	14.7^{b}
	118	25	A4	0.1^{c}	12^{b}	35.0^{a}	18.8^{b}	17^{a}	10.7^{b}
Average	486	100	A1	0.4^{a}	40^{a}	53.8^{a}	36.6^{a}	24^{a}	36.8^{a}
	364	75	A2	0.3^{b}	37^{a}	46.0^{ab}	32.5^{a}	19^{a}	36.0^{a}
	243	50	A3	0.3^{b}	19^{b}	31.9^{ab}	16.1^{b}	15^{a}	15.5^{b}
	121	25	A4	0.2^{c}	14^{b}	29.9^{b}	16.7^{b}	15^{a}	11.2^{b}

Different letters indicate a significant difference in the level 1% probability using Duncan's test.

Table 7. Percentage of essential oil and dry matter compared to control treatment.

Year	Irrigation Levels (%)	Percentage of essential oil compared to control treatment (%)	Percentage of dry matter compared to control treatment (%)
2017	100	100	100
	75	75	88
	50	75	41
	25	50	44
2018	100	100	100
	75	60	89
	20	60	47
	25	20	47
Average	100	100	100
	75	68	89
	50	68	44
	25	50	46

3.2. The effect of deficit irrigation on dry matter and essential oil yield

The results of the percentage of essential oil and dry matter in the studied treatments compared to the control treatment (treatment with irrigation level of 100% of plant water requirement) are measured, compared and presented in Table 7. The results in Table 7 show a decrease in the percentage of essential oil by (68, 68 and 50) and dry matter by (89, 44 and 46) percent, as a result of applying irrigation treatments of 75, 50 and 25% compared to full irrigation. Also, according to Fig. 1, the downward slope of the essential oil obtained from the 75% treatment corresponds to the slope of the 100% water requirement treatment. This indicates that the reduction of water requirement from 100% to 75% has a direct effect on the amount of essential oil. However, there are no significant differences in the essential oils of 75% and 50% water requirements, but this difference was significant in the treatment of 25% of water requirement. Fig. 2 also shows that there was no significant difference between the amounts of dry matter obtained in treatments 100 and 75 of the water requirement and if the purpose of rosemary cultivation was to produce dry matter, the desired product can be achieved with 75% of water requirement.

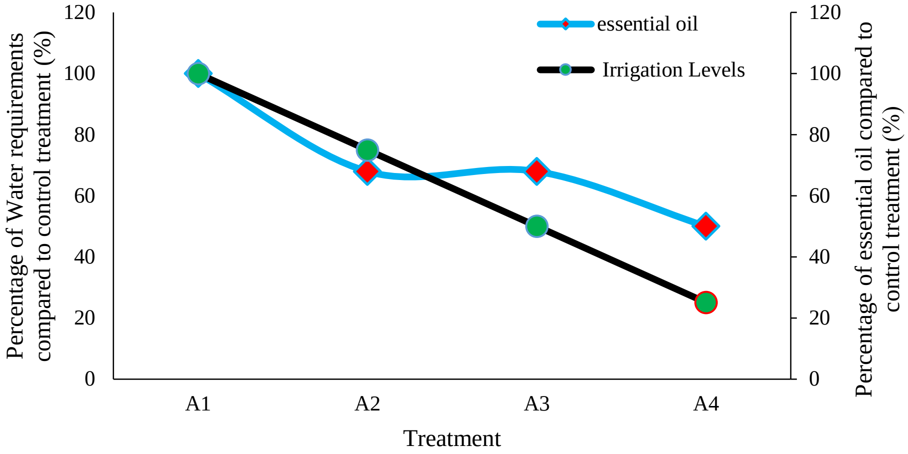

Figure 1. Comparison of essential oil percentage and percentage of water consumption of treatments compared to control treatment.

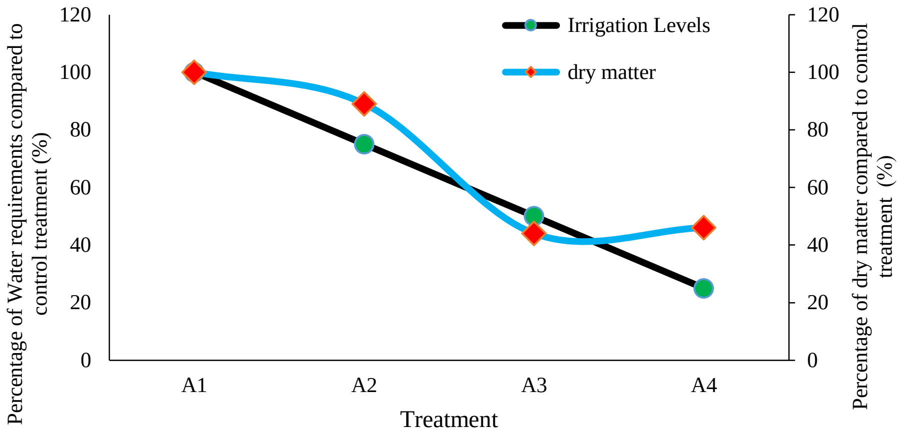

Figure 2. Comparison of dry matter percentage and percentage of water consumption of treatments compared to control treatment.

Rosemary plant height is one of the most effective indicators of determining the yield (dry weight of shoots) of the rosemary plant (Leithy *et al.*, 2006). According to Table 6, deficit irrigation had a significant effect on plant height and treatment of 25% of water requirement compared to full irrigation had a 65% reduction in the amount of this parameter. In a study entitled Quantitative evaluation of rosemary characteristics using two drip irrigation systems under the influence of low irrigation, comparing the average plant height showed that the effect of different irrigation treatments on this trait is significant So that full irrigation in the subsurface drip method caused the highest plant height and the results showed that irrigation at 75% of the water requirement in the subsurface irrigation method caused a 32.3% reduction in plant height compared to full irrigation (Asadi *et al.*, 2019). Which was consistent with the results of the present study.

Based on past research one of the most important reasons for the decrease in plant weight during the stress period can be considered as the adverse effects of stress on plant growth indices such as plant height (Dehghani bidgholi, 2018). These findings were in agreement with the results of a study that reported that water stress had a significant effect on plant fresh weight, plant dry weight, stem fresh weight, stem dry weight, leaf fresh weight, and dry leaf weight of thyme and they also acknowledged that deficit irrigation reduced the yield in the mentioned traits (Bani Asadi *et al.*, 2015).

According to Table 6, applying deficit irrigation at the level of 25% of water requirement in wet and dry weight of the plant in comparison with full irrigation has reduced the yield of these parameters by 44.42 and 54.37%, respectively. Extensive research has been done on the application of under-irrigation on the yield of various crops, most of which are in line with the results obtained in the present study. In a study, deficit irrigation on maize was investigated and the results showed that supplying 60% of the water required by the plant reduces the dry weight of the stem by 30% compared to full irrigation (Palash *et al.*, 2022).

In another study, the effect of the deficit irrigation regime on biomarkers of two local cultivars of Agvin was investigated and the results showed that by changing the low irrigation levels from 100 to 50% of field capacity, grain yield, essential oil yield, biological yield, and 1000-seed weight were associated with a decrease (Jami AlAhmadi, 2020).

Applying deficit irrigation on the Number of branches in rosemary reduced the yield by 37.5% in irrigation treatment by 25% of the water requirement compared to complete irrigation treatment (Table 6). Irrigation has a significant effect on vegetative growth and consequently the number of branches of plants. By applying deficit irrigation to rosemary, vegetative growth is reduced and as a result, less fertile branches are produced. In most studies on the effect of irrigation cycle and drought stress on morphological factors of different plants, it has been found that with decreasing irrigation, the number of sub-branches also decreases Among these cases, we can mention a study that showed that by increasing the irrigation cycle from 2 days to 10 days, there was a significant reduction in the number of sub-branches in chamomile (Razmjoo *et al.*, 2008).

Examination of root depth showed that irrigation at 25% of water requirement reduced the yield of this parameter by 69.56% compared to full irrigation treatment. Based on the results obtained in a similar study on the effect of deficit irrigation on root distribution and vegetative growth of rosemary, the results showed that deficit irrigation adjusted to 55% of water requirement reduced root length by 33.90% compared to full irrigation. Which is consistent with the results of the present study (Asadi *et al.*, 2019).

According to the results of the present study, deficit irrigation caused a decrease in essential oil yield which is consistent with the results of some research (Jami AlAhmadi, 2020; Omidbeigi, 2010). One of the reasons for the reduction of essential oil by water stress can be related to the reduction of yield and yield components of rosemary. In most studies, it has been pointed out that with increasing environmental stress, the percentage of essential oil increases, which was not achieved in this study. Other reasons for this result can be the involvement of other factors such as climate and soil and nutritional factors in the amount of essential oil and essential oil yield.

4. Conclusion

Based on the results obtained in this study, increasing the level of deficit irrigation significantly ($P \leq 0.01$) affected the components of root depth, essential oil, dry matter, in rosemary and reduced all indicators (except the branches number) compared to the control treatment. According to the obtained results, if the purpose of cultivating rosemary was to produce dry matter, the desired product can be achieved with 75% of the water requirement. On the other hand, if the purpose of cultivating was to produce essential oil, the full water requirement of the plant must be met. Finally, due to the reduction of all plant parameters, the amount of essential oil and dry matter yield due to water stress with a deficit irrigation level of 50% in rosemary was not seem reasonable and not recommended, but irrigation at 75% of the water requirement in rosemary was justifiable and acceptable.

Conflict of interests

All authors declare no conflict of interest.

Ethics approval and consent to participate

No human or animals were used in the present research.

Consent for publications

All authors read and approved the final manuscript for publication.

Availability of data and material

All the data are embedded in the manuscript.

Authors' contributions

All authors had an equal role in study design, work, statistical analysis and manuscript writing.

Informed consent

The authors declare not to use any patients in this research.

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