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Research Article

Response of Rosemary (*Rosmarinus officinalis* L.) for Growth Stage based Deficit Irrigation at Wondo Genet, Ethiopia

Ayele Debebe*, **Elias Meskelu, Henok Tesfaye, Seble Bekele, Yitagesu Nurga**

Department of Agricultural Sciences, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia

ABSTRACT

Growth stage based deficit irrigation is an important way of managing irrigation water by identifying the most sensitive growth stages to apply the required amount of water on these sensitive growth stages. A field experiment was conducted at Wondo Genet Agricultural Research Center, Ethiopia, latitude 8°25'59", longitude 39°01'44" and altitude of 1800 m.a.s.l to investigate the effect of water stress at different growth stage on yield and water productivity of rosemary. A combination of four deficit levels (100%, 85%, 70% and 55% ETc) and four growths stages (initial, development, mid and late) were used as treatments with three replications to evaluate the yield and yield component of rosemary in split plot arrangement. Different growth stage based deficit irrigation significantly affected all recorded yield and yield components of rosemary including its water productivity. Significantly higher yield and yield components were associated with treatments that receive 100% ETc at all growth stages and lowest one was recorded on treatments that receive 55% ETc at mid growth stage. Mid stage was sensitive to moisture stress than other growth stages. Therefore, for better production of rosemary avoiding moisture stress at mid stage is needed and stressing other growth stages up to 70% ETc is possible or has no that much impact on yield and yield component of rosemary.

Keywords: Deficit irrigation; Essential oil; Rosemary; Water use efficiency

INTRODUCTION

Rosemary (*Rosmarinus officinalis* L.) is an evergreen woody aromatic herb having a characteristic aroma and lavender-like leaves. The dried material and oil of rosemary obtained from the leaves and flowering tips of rosemary are extensively used in the food, flavor and fragrance industries. Rosemary oil is also used in aromatherapy [1].

Deficit irrigation is an optimal use of limited water resources by applying irrigation water to crop at its most water stress sensitive growing period. Deficit irrigation, the application of water below full crop water requirement is an important tool in reducing irrigation water use, thus increasing irrigation efficiency. Although reduction in yield is expected when plants are subjected to water stress, the level and timing of the stress should be such that the resulting yield reduction is small when compared to the benefits gained. In order for deficit irrigation to be successfully implemented, a crop's response to the different levels of stress at various times during its growth period needs to be known.

Growth stage based deficit irrigation is an important way of managing irrigation water by identifying the most sensitive growth stages to apply the required amount of water on these sensitive growth stages. In this practice full irrigation water is applied only in the sensitive growth stages and a certain level of deficit irrigation can be applied on the growth stages that are not sensitive to water stress [2]. Worldwide these types of research are common to identify crops sensitive growth stages in water scare areas. For instance, Zhang et al., try to identify response of maize yield components to growth stage-based deficit irrigation and reported that water deficit applied during the maturity stage had a larger impact on maize yield compared with water deficit

*Corresponding author: Ayele Debebe, Department of Agricultural Sciences, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia; E-mail: ayedebebe12@gmail.com

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applied during the vegetative stage. Jin et al., also try to identify the responses of maize yield and water use to growth stage based irrigation on the Loess Plateau in China and reported that when irrigation water is limited, high WUE can be achieved if it is applied at vegetative growth stages, while high yield can be achieved if more available water is applied at tasseling stage.

However, there are information gap on growth stage based deficit irrigation for rosemary production under irrigation in the study area. So the study was conducted to identify the most sensitive growth stage to deficit irrigation and to investigate the effect of water stress at different growth stage on yield and water productivity of rosemary.

MATERIALS AND METHODS

Description of the experimental site

The study was carried out at Wondo Genet Agricultural Research Center, Koka Research Site, Ethiopia, for three consecutive years (2019/2020 to 2021/2022) during the dry period (October to June) based on an objective to identify the most sensitive growth stage to deficit irrigation and to investigate the effect of water stress at different growth stage on yield and water productivity of rosemary. Geographically the experimental plot was situated at 8°26' N latitude, 39°02' longitude and altitude of 1602 m.a.s.l. Clay is the dominant soil texture in the study area in which the field capacity and permanent wilting point of the soil in the rooting depth found to be 33.5% and 19.0%, respectively. The bulk density of the soil was 1.1 g/cm^3. These leads to a volumetric available water holding capacity per unit meter of the soil profile in the root zone to be 160 mm [3]. The climate of the study area characterized as semi-arid with mean annual rainfall of 831 mm from which only 9.7% fall during the dry season (October to February) and the rest majority of the annual rainfall, falls from March to September (Table 1).

Table 1: Long-term monthly climatic data of the experimental area.

Month	T_{min} (°C)	T_{max} (°C)	RH (kpa)	Wind speed (m/s)	Sunshine hours (%)	RF (mm)
January	11.33	27.44	1.336	4.04	75	13.45
February	12.57	28.25	1.387	4.08	76	26.06
March	14.44	30.04	1.503	4.64	74	51.49
April	15.17	30.32	1.635	3.8	71	58.48
May	15.12	30.86	1.63	3.98	68	48.45
June	15.52	30	1.701	4.91	65	72.72
July	15.04	26.67	1.736	4.3	54	212.71
August	15.09	26.33	1.752	3.15	53	202.39
September	14.89	27.82	1.786	2.3	57	104.32
October	12.65	28.33	1.48	3.5	73	21.1
November	11.3	27.39	1.304	4.09	83	9.85
December	10.98	26.14	1.258	4.19	76	9.88

Experimental design and procedure

The field experiment was carried out using split plot arrangement with three replications. The plot size used was 3.00 m × 3.00 m with spacing of 1.50 m between sub plots and 2.00 m between main plots and 3.00 m between blocks. Treatments that receive different levels of deficit at different growth stages were: (1) 100% ETc at initial, (2) 85% ETc at initial, (3) 70%ETc at initial, (4) 55% ETc at initial, (5) 100% ETc at development, (6) 85% ETc at development, (7) 70% ETc at development, (8) 55% ETc at development, (9) 100% ETc at mid, (10) 85% ETc at mid, (11) 70% ETc at mid, (12) 55% ETc at mid, (13) 100% ETc at late, (14) 85% ETc at late, (15) 70%ETc at late, and (16) 55% ETc at late growth stage [4].

Rosemary seedling was prepared in nursery for two months prior to plantation time during the rainy season. For seedling preparation, top cutting position was used as per the recommendation for the area for better seedling using stem cutting from one year old rosemary collected from multiplication plots at Wondo Genet Agricultural Research Center. After good establishment of seedling at nursery with average height of 25 cm, it was transplanted to the field with population density recommended for the area which was 60 cm between rows and 60 cm between plants in the row. Prior to planting the land preparation was done with plowing, land leveling and layout according to the experiment. During the study period, regular tillage and agricultural operation for rosemary in the study area were followed beyond the irrigation level as it is applied according to the treatment arrangement. Irrigation water was applied based on to refill the soil to field capacity in the control plot which receives all stage. Accordingly based on their deficit levels and stages with the same date was applied for treatments to be irrigated in the particular growth stage. All other agronomic practices were similar for all plots as per the recommendation for the area [5].

The calculated gross irrigation depth for each treatment was applied using Parshall flume of size 2-inch. For these soil samples before irrigation was taken to determine the moisture content of the soil using gravimetric method. Next irrigation applied when the moisture depletion level in the control plot attain 60% from the total available water for all season.

Data collection and analysis

Rosemary yield and yield components were collected from central five plants in the plot excluding border rows. Field data on plant height was collected from these samples by measuring their height using tape and the mean was calculated. For other yield and yield component data, the selected five samples were harvested by using sickle. Harvesting was done 270 days after planting for essential oil yield production. The collected sample was then submitted to Wondo Genet Agricultural Research Center, Natural Product Laboratory for extraction of essential oil using hydro distillation method and determination of moisture content using oven dry as illustrated by Guenther. Dry leaf weight, dry stem weight, essential oil yield and dry biomass yield were calculated based on the results of oil content and moisture content from the laboratory [6]. Moreover, based on essential oil yield and amount of irrigation used for each treatment, water use efficiency was calculated using the following formula.

$$\text{Water use efficiency } (\text{kg/m}^3) = \frac{\text{Essential oil yield } \left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Net irrigation water applied } \left(\frac{\text{m}^3}{\text{ha}}\right)}$$

The collected data were analyzed using Statistical Analysis System (SAS) version 9.3 procedure of general linear model for the variance analysis. Mean comparisons were carried out to estimate the differences between treatments using Fisher's Least Significant Difference (LSD) at 5% probability level.

RESULTS AND DISCUSSION

Different growth stage based deficit irrigation significantly affected all recorded yield and yield components of rosemary including its water productivity. Significantly higher yield and yield components were associated with treatments that receive 100% ETc at all growth stages and lowest one was recorded on treatments that receive 55% ETc at mid growth stage.

Plant height

The study showed that plant height of rosemary was highly significantly ($p<0.01$) affected by different levels of soil moisture deficit at different growth stages. Maximum plant height (139.7 cm) was recorded at 100% ETc at late stage (Table 2). However, this was statistically similar to that of 100% and 85% ETc at initial, development and mid stage and 70% ETc at initial stage. On the other hand, minimum plant height (119.0 cm) was recorded at 55% ETc at mid stage which is statistically similar to that of 55% ETc at initial, development and late stage and 70% ETc at mid and late stage (Table 2).

Table 2: Response of rosemary for growth stage based deficit irrigation

Treatment	PH	LFW	FBM	EOY	WUE*1000
	(cm)**	(t/ha)**	(t/ha)*	(Kg/ha)	(Kg/m^3)*
Initial S. 100% Etc	139.5^{a}	19.7^{a}	33.6^{a}	82.7^{a}	7.1^{bcd}
Initial S. 85% Etc	137.2^{a}	17.8^{ab}	32.0^{ab}	74.8^{ab}	5.9^{d}
Initial S. 70% Etc	138.4^{a}	16.4^{bc}	27.0^{b}	68.9^{bc}	7.8^{bcd}
Initial S. 55% Etc	130.6^{b}	16.5^{bc}	27.6^{b}	69.3^{bc}	8.0^{abcd}
Dev't S. 100% Etc	140.2^{a}	19.6^{a}	34.1^{a}	82.3^{a}	7.2^{bcd}
Dev't S. 85% Etc	136.8^{a}	19.7^{a}	34.1^{a}	82.7^{a}	8.1^{abcd}
Dev't S. 70% Etc	131.1^{b}	18.2^{ab}	32.0^{ab}	76.4^{ab}	9.2^{ab}
Dev't S. 55% Etc	125.6^{bc}	14.6^{bc}	27.3^{b}	61.3^{bc}	6.4^{cd}

Mid S. 100% Etc	137.5^{a}	18.9^{ab}	33.1^{ab}	79.4^{ab}	5.8^{d}
Mid S. 85% Etc	126.7^{bc}	16.9^{b}	28.1^{b}	71.0^{b}	126.7^{bc}
Mid S. 70% Etc	124.1^{bc}	14.6^{bc}	26.0^{bc}	61.3^{bc}	10.1^{a}
Mid S. 55% Etc	119.0^{c}	14.1^{c}	22.5^{c}	59.2^{c}	8.0^{abcd}
Late S. 100% Etc	139.7^{a}	18.3^{ab}	31.3^{ab}	76.9^{ab}	7.2^{bcd}
Late S. 85% Etc	134.3^{ab}	17.5^{ab}	31.0^{ab}	73.5^{ab}	7.6^{bcd}
Late S. 70% Etc	125.1^{bc}	15.9^{bc}	28.9^{b}	66.8^{bc}	6.2^{d}
Late S. 55% Etc	125.3^{bc}	15.5^{bc}	28.3^{b}	65.1^{bc}	8.5^{abc}
CV (%)	4.2	9.7	8.4	9.4	18.4
LSD@0.05	8.8	2.7	4.2	11.3	2.3

Note: Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at p<0.05 level of significance; ns: non-significant at p<0.05; *significant at p<0.05; **significant at p<0.01; PH: Plant Height; FLW: Fresh Leaf Weight; FBM: Fresh Biomass; EOY: Essential Oil Yield; WP: Water Productivity; CV: Coefficient of Variation; LSD0.05: Fisher's least significant difference at 5% probability level.

The result showed that rosemary plant was more sensitive to water stress at mid stage than other growth stages and in this stage when the stress level increase plant height become shortest. This might be due to the adverse effects of deficit soil moisture stress on plant growth, development and yield which lead to loss of turgidity leading to cell enlargement and stunted growth, decrease in photosynthesis due to decreased diffusion of CO_2 with the closure of stomata to conserve water and reduced leaf area. Similar studies also showed that plant height is affected due to growth stage based moisture stress in different crops. This finding in lined with Meskelu et al., who reported that Artemisia plant height was decreased due to moisture stress at development and mid growth stages [7]. Ghamarnia et al., also reported that rosemary plant height was decreased due to deficit irrigation which is in lined with the current finding.

Leaf fresh weight

The study showed that leaf fresh weight of rosemary was highly significantly (p<0.01) affected by different levels of soil moisture deficit at different growth stages. Maximum leaf fresh weight (19.7 t/ha) was recorded at 100% ETc at initial stage (Table 2). However, this was statistically similar to that of 100% ETc at initial, development and mid stage, 85% ETc at development and late and 70% ETc at development stage. On the other hand, minimum leaf fresh weight (14.1 t/ha) was recorded at 55% ETc at mid stage which is statistically similar to that of 55% ETc at initial, development and late stage and 70% ETc at mid and late stage (Table 2).

The result showed that increasing soil moisture deficit at mid growth stage leads for reduction of leaf fresh weight of rosemary. This showed that rosemary was sensitive to water stress at mid growth stages than other growth stages. The finding was in lined with Tesfaye et al. who reported that Artemisia leaf fresh weight was decreased as soil moisture deficit level increased.

Fresh biomass

The study showed that fresh biomass of rosemary was significantly (p<0.05) affected by different levels of soil moisture deficit at different growth stages. Maximum fresh biomass (34.1 t/ha) was recorded at 100% ETc at development stage (Table 2). However, this was statistically similar to that of 100% ETc at initial, development and mid stage, 85% ETc at initial, development and late and 70% ETc at development stage [8]. On the other hand, minimum fresh biomass (22.5 t/ha) was recorded at 55% ETc at mid stage which is statistically similar to that of 70% ETc at mid stage (Table 2).

The result showed that when rosemary was stressed at mid stage fresh biomass was decreased. Zhang et al., reported that maize biomass was decreased due to moisture stress at late vegetative stages which is in lined with the current finding. Tesfaye et al. on Artemisia and Ghamarnia et al. on Rosemary also reported the same finding, fresh biomass were decreased due to deficit irrigation.

Essential oil yield

The study showed that essential oil yield of rosemary was highly significantly (p<0.01) affected by different levels of soil moisture deficit at different growth stages. Maximum essential oil yield (82.7 kg/ha) was recorded at 100% ETc at initial stage (Table 2). However, this was statistically similar to that of 100% ETc at initial, development and mid stage, 85% ETc at development and late and 70% ETc at development stage. On the other hand, minimum essential oil yield (59.2 kg/ha) was recorded at 55% ETc at mid stage which is statistically similar to that of 55% ETc at initial, development and late stage and 70% ETc at mid and late stage [9].

The result showed that higher level of soil moisture deficit at mid growth stage gave lowest essential oil yield. The study revealed that higher essential oil yield associated with application of higher irrigation water depth. This might be due to higher biomass production. The finding was similar with that of Meskelu et al. who reported that essential oil yield of lemongrass was decreased as soil moisture deficit increased. Ghamarnia et al. on Rosemary also reported the same finding; essential oil yield was decreased due to deficit irrigation.

Water productivity

The study showed that water productivity of rosemary was highly significantly ($p<0.01$) affected by different levels of soil moisture deficit at different growth stages. Maximum water productivity (10.1 kg/m^3) was recorded at 70% ETc at mid stage (Table 2). However, this was statistically similar to that of 55% ETc at initial, mid and late stage, and 85% and 70% ETc at development stage. On the other hand, minimum water productivity (5.8 kg/m^3) was recorded at 100% ETc at mid stage which is statistically similar to that of 100% and 85% ETc at initial, development and late stage and 55% ETc at initial, development and mid stage (Table 2).

The result showed that treatments that receive larger amount of irrigation water gave lower water use efficiency and treatments that receive small amount of irrigation water gave highest water use efficiency. The finding was similar with that of Nakawuka et al. who reported that water use efficiency of spearmint was improved by deficit irrigation. Applying irrigation during vegetative stages could accelerate increases in leaf area, light interception and photosynthesis and thus, increase yield per total plant water consumption [10]. However, stress during vegetative stages may precondition plants to tolerate greater drought stress during later stages in crop development, such as the grain-filling stage in maize. So, the appropriate timing for applying water deficits to achieve the highest water productivity must be identified clearly.

CONCLUSION

Growth stage based deficit irrigation significantly affected all recorded yield and yield components of rosemary including its water productivity. Significantly higher yield and yield components were associated with treatments that receive 100% ETc at all growth stages and lowest one was recorded on treatments that receive 55% ETc at mid growth stage. Mid stage was sensitive to moisture stress than other growth stages. Therefore, for better production of rosemary avoiding moisture stress at mid stage is needed and stressing other growth stages up to 70% ETc is possible or has no that much impact on yield and yield component of rosemary.

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REFERENCES

1. Geerts S, Raes D. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agric Water Manag. 2009;96(9):1275-1284.
2. Ghamarnia H, Palash M, Amiri S. Deficit irrigation effects on rosemary plant (*Rosmarinus officinalis* L.) parameters in a semi-arid climate. Agrotech Ind Crops. 2022;2(2):57-64.
3. Harb A, Krishnan A, Ambavaram MM, Pereira A. Molecular and physiological analysis of drought stress in Arabidopsis reveals early responses leading to acclimation in plant growth. Plant Physiol. 2010;154(3):1254-1271.
4. Jin N, He J, Fang Q, Chen C, Ren Q, He L, et al. The responses of maize yield and water use to growth stage-based irrigation on the loess plateau in China. Int J Plant Prod. 2020;14:621-633.
5. Meskelu E, Debebe A, Tesfaye H, Mohammed M. Response of lemongrass (*Cympopogon citratus* (DC) Stapf) to deficit irrigation and furrow irrigation water application methods at Wondo Genet, Ethiopia. Irrigat Drainage Sys Eng. 2019;8(230):2.
6. Meskelu E, Debebe A, Tesfaye H, Mohammed M, Bekele S. Response of Artemisia (*Artemisia annua* L.) for moisture stress condition at different growth stages at Koka, Ethiopia. Agrotechnology. 2021;10:206.
7. Nakawuka P, Peters TR, Gallardo KR, Toro-Gonzalez D, Okwany RO, Walsh DB. Effect of deficit irrigation on yield, quality, and costs of the production of native spearmint. J Irrig Drain Eng. 2014;140(5):05014002.
8. Singh M. Effects of plant spacing, fertilizer, modified urea material and irrigation regime on herbage, oil yield and oil quality of rosemary in semi-arid tropical conditions. J Hortic Sci Biotech. 2004;79(3):411-415.
9. Tesfaye H, Debebe A, Meskelu E, Mohammed M. Effects of deficit irrigation and furrow application methods on yield and yield components of *Artemisia annua* L. at Koka, Ethiopia. Agrotechnology. 2021;10:208.
10. Zhang H, Han M, Comas LH, DeJonge KC, Gleason SM, Trout TJ, et al. Response of maize yield components to growth stage-based deficit irrigation. Agron J. 2019;111(6):3244-3252.