ISSN 2229-5518

Effect of Soil Type and Water Content on Rosemary Growth and Essential Oil Yield

Fatma Gharib[1], Safia Ghazi[1], Hebatallah Aly[1], Magda El-Araby[2], and Seham Moustafa[2*]

[1]Department of Botany and Microbiology, Faculty of Science, Helwan University, Cairo, Egypt
[2]Department of Botany, Faculty of Science, Ain Shams University, Cairo, Egypt
*Corresponding author, E-mail: sehammoustafa@yahoo.com

Abstract— This study aimed to investigate the effect of two types of soil: sandy clay (SC) and sandy loam (SL) and two irrigation systems: once (I1) and twice (I2) per week, with each soil, on the growth criteria and productivity of essential oil (EO) in rosemary (*Rosmarinus officinalis* L.) during two cuts at February and August (3, 9 months from transplanting, respectively). Cultivation in SL soil and I2 irrigation system, followed by SL and I1, significantly increased the growth characters as well as the yield of EO of rosemary plants during the two cuttings, as compared to those in corresponding plants cultivated in the SC soil. With all treatments, the above mentioned parameters were generally higher at the 2nd cut, compared to those at the 1st cut. In the SC soil, I1 irrigation system was more effective than I2 irrigation with respect to the vegetative growth rate at the first cut, whereas the reverse was obtained at the second cut. Within the different treatments, the enhancement of plant growth was generally proportional with the increase in leaf area and chlorophyll contents, whereas a negative correlation was observed between the carotenoid contents and soil moisture. Generally, planting in the SL soil concomitant with I1a and I2 irrigation, effectively increased the oil yield (% and l/fed) during the two cuttings, compared to corresponding plants grown in the SC soil. In conclusion, rosemary plants could maximize the growth characters and EO content in sandy loam habitat combined with I2 irrigation, Irrespective of the applied treatment. The productivity of EO was higher at the second cut than the first one.

Index Terms— Growth traits, Irrigation systems, Oil Content, *Rosmarinus officinalis*, Soil type.

INTRODUCTION

Rosemary (*Rosmarinus officinalis* L.) is an aromatic plant, grown under a wide range of climates, endogenous to Europe, Asia and Africa, mainly in areas surrounding the Mediterranean Sea [1]. It is an evergreen, perennial herb well cultivated in Egypt and available throughout the year. It is one of the most effective spices widely used in food processing among the herbs of family Labiatae. The plant and its extracts are among the first marketed natural antioxidants [2]. Rosemary extract may be a good candidate for functional foods as well as for pharmaceutical plant-based products [3, 4]. The use of many essential oils of many plants including rosemary has been reviewed by Ali et al. [5].

In the past few years, rosemary has been successfully cultivated in warm and dry climates of arid and semiarid regions. However, as in the majority of cultivated plants, growth and yield of rosemary is mainly affected by both soil type and water content. Deficit irrigation altered the morphology of *R. officinalis* plants [6], reduced growth parameters, oil yield, relative water content and photosynthetic productivity [7, 8].

Soil pores play an important role not only on soil aeration and water movement but also on the availability of plant nutrients and microbiological activities [9]. In *Centella asiatica*, maximum growth and yield were recorded in habitat with sandy loam rather than clay soil [10]. In *Hibiscus sabdariffa*, all growth and yield attributes were significantly increased under moderate moisture levels in sandy soil [11].

Water is also vital for plant growth and development, but water resources need to be used efficiently because of global warming [12]. Increasing competition for the limited water resources between domestic, industrial and agricultural consumptions has increased the importance of irrigation scheduling [13]. Deficit irrigation is a water management method in which water will be saved with accepting little yield reduction without any severe damage to the plant [14]. This system can lead to increased water productivity, not only in terms of output per volume of applied water, but in many cases with crop quality, and/or economic returns [15, 16]. In *Calendula officinalis*, water regimes of 75% field water capacity, increased certain growth characters (plant height, leaf area and flower diameter) [17].

Thus, our main objectives were to study the variation in growth traits and yield of essential oil of rosemary (*Rosmarinus officinalis*) plants grown in different soil types under irrigation with different water contents at two cuttings; one in winter (February) and the other in summer (August). Consequently, a strategy for minimum irrigation water, in a certain soil type (particularly sandy soil), would be intended for maximum productivity.

2 MATERIALS AND METHODS

PLANT MATERIAL

Uniform transplants of rosemary (*Rosmarinus officinalis* L.) were kindly provided by the Medicinal and Aromatic Plant Research Branch, El-Qanatir El-Khairiya, Horticulture Research Institute, Ministry of Agriculture, Cairo, Egypt.

TIME COURSE EXPERIMENT

A pot experiment was conducted at the green house of the Botanic garden, Faculty of Science, Ain Shams University, Cairo, Egypt, at November 2013 to August 2014. Rosemary was grown under two soil types and two irrigation water levels throughout the two cuts of the experiment. During the experiment, the minimum and maximum temperatures inside the greenhouse were 14.6°C and 32.1°C, respectively. Mean temperature and relative humidity were, 16.8°C and 56.25 %, during November and 23.8°C and 56.8%, during August. The pots were divided into four groups; each including thirty plastic pots (30 cm diameter and 18 cm in depth). Three uniform transplants (60 day- old) of rosemary were planted in each pot. Each pot was filled with one type of soil, i.e. either sandy clay (SC) or sandy loam (SL) soil. When the plants were well established, the irrigation system was applied once (I1) or twice (I2)/week with each soil type.

The pots were arranged in complete randomized block designs with the different treatments. Two cuts (3 and 9 months from transplantation) were taken for experimentation.

ANALYSIS OF SOIL AND IRRIGATION WATER

Analyses of physical and chemical properties of the soil types used in this study were done as described by Cottenie et al. [18].

MEASUREMENT OF SOIL WATER CONTENT

Soil water content was determined in 100 g soil, where the reduction in mass by oven drying (105°C) was due to loss of water.

ISSN 2229-5518

Growth Criteria

At the full blooming stage, plants (10 replicates) were randomly collected early in the morning from each of the experimental groups, carefully washed with distilled and then different growth parameters were recorded. Mean leaf area was estimated using digital Image Analysis (Image J version 1.46r/java). Dry weights were obtained by drying plant samples in an oven with drift fan at 75°C until constant weights. Representative fresh samples were taken from each treatment for determination of photosynthetic pigments and essential oil contents.

Photosynthetic Pigments

Photosynthetic pigments including chlorophyll (a and b) and carotenoids of fresh rosemary leaves were extracted in 80% (v/v) acetone and measured spectrophotometrically according to the procedure of Metzener et al [19]. The results were calculated as mg/g dry weight equivalent.

Extraction and Determination of Essential Oil Contents

Quantitative determination of essential oil (EO) from fresh samples of rosemary herb was achieved by hydro-distillation for 3 hours using a Clevenger-type apparatus during the two cuttings. Essential oil percentage (%) and yield (l/fed) were calculated on a dry weight basis.

Statistical Analysis

The data were expressed as mean ± standard error (SE) of ten replicates values for growth criteria and as mean ± standard error (SE) of triplicate values for the oil content (percentage and yield). Statistical analysis was performed using one-way analysis of variance ANOVA followed by Duncan's Multiple Comparison Test using IBM Statistical Product and Service Solutions, SPSS Statistics for Windows, Version 21, and P<0.05 was denoted as being statistically significant for the means compared, using least significant difference (LSD at 5% level).

Results

Analysis of Soil and Irrigation Water

The physical and chemical properties of the soil used (S1 and S2) indicated a sandy clay (SC) and sandy loam (SL) structures, respectively. Other physical properties of both soil types are shown in Table 1. The chemical analysis of both types of soil (Table 1) indicated a higher Cl^- content in the SC soil and a higher Ca^{++} and CO_3^- contents in the SL soil, as compared with one another. On the other hand, slight differences were observed with regard to the contents of the other ions.

Table 1: Physical and chemical characteristics of the sandy clay (SC) and sandy loam (SL) soil samples from the Botanical garden (Faculty of Science, Ain Shams University) used for cultivation of rosemary plants in the pots experiment.

Soil type	Physical Properties			Soil texture	pH	EC* (dS/m)	SP* (%)	Cations and anions (mg/Kg)								Ca CO_3	Organic matter
	Sand (%)	Silt (%)	Clay (%)					Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO^-	CO_3^{--}	SO_4^{--}	(%)	(%)
1	39.2	24.0	26.8	SC	7.91	0.31	36	7.5	2.8	12.2	9.9	16.6	13.1	0.0	55.3	2.0	1.5
2	61.5	18.9	8.3	SL	8.1	1.26	29.3	8.2	3.04	16.2	10.3	12.6	14.3	2.09	49.8	2.8	1.02

SC: Sandy clay; SL: Sandy loam; EC = Electrical conductivity; SP = Saturation percent

Analysis of irrigation water showed that it is slightly alkaline, with low salinity and mild ratios of ions (Table 2).

Table 2: Chemical analysis of the irrigation water sample from the Botanical garden (Faculty of Science, Ain Shams University), where rosemary plants were cultivated.

pH	EC*(dS/m)	TDS (ppm)	Cations and anions (mg/l)							
			Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	CO_3^{--}	SO_4^{--}
7.72	0.41	262	33.1	5.2	42.0	11.3	28.4	140.3	0.0	69.1

EC*: Electric conductivity (dS/m); TDS: Total dissolved solids (ppm) Growth parameters

The results presented in Tables 3 and 4 show the effect of soil types; i.e. sandy clay (SC) and sandy loam (SL) and their combinations with the irrigation systems as once or twice per week (I1 or I2) on the growth criteria (length of roots and shoots, leaf area/ plant, No. of branches /plant, and the root and shoot fresh and dry weights) of rosemary (*Rosmarinus officinalis* L.) plants at two cuts (February and August, respectively). In most cases, the enhancements in growth parameters were often significantly higher for the plants grown in the SL and I2 irrigation (at the first and second cuts), as compared with those in the SC soil. Plant growth was in the SC soil better with I1 than with I2 irrigation at the first cut (Figure 1 and Table 3), but a reverse situation was obtained at the second cut where plant growth was higher with I2 irrigation (Table 4).

Figure1: Growth of rosemary (*Rosmarinus officinalis* L.) at the 1st cut (3 months from transplanting) as influenced by cultivation in sandy clay (SC) or sandy loam (SL) soil, and irrigation once/week (I1) or twice/week (I2) with each soil type.

Table 3: Growth criteria of rosemary (*Rosmarinus officinalis* L.) at the 1st cut (3 months from transplanting) as influenced by sandy clay (SC) or sandy loam (SL)s soil, and irrigation once/week (I1) or twice/week (I2) with each soil type. Transplants (60 day old) were cultivated during the season (November). Each result is a mean of 10 replicates ± SE. Statistical analysis was carried out using Duncan test. Different letters show significant variation at 0.05 P.

Treatment / Criteria	SC		SL	
	Irrigation/week		Irrigation/week	
	I1	I2	I1	I2
Plant height (cm)	41.29±0.08 a	35.53±0.12 c	40.03±0.24 b	41.60±0.10 a
Mean number of branches/plant	5.53±0.11 c	5.39±0.09 c	5.87±0.12 b	6.24±0.07 a
Mean length of branches/plant (cm)	26.38±0.08 b	25.46±0.10 c	29.51±0.18 a	29.72±0.12 a
Mean length of roots (cm)/plant	14.15±0.11 c	13.86±0.05 d	14.64±0.10 b	15.15±0.06 a
Mean number of roots /plant	5.92±0.05 b	5.42±0.12 c	5.93±0.12 b	6.75±0.10 a
Mean area of leaf (cm ^{2}2)	0.94±0.01 c	0.63±0.01 d	0.98±0.01 b	1.04±0.01 a
Root fresh weight (g)	4.34±0.08 b	3.43±0.05 c	5.08±0.13 a	5.26±0.11 a
Shoot fresh weight (g)	21.95±0.10 c	17.53±0.18 d	22.45±0.16 b	24.57±0.12 a
Root dry weight (g)	1.85±0.04 b	1.40±0.03 c	2.45±0.02 a	2.56±0.13 a
Shoot dry weight (g)	8.84±0.04 c	6.76±0.07 d	9.16±0.06 b	9.92±0.05 a

Table 4: Growth criteria of rosemary (*Rosmarinus officinalis* L.) at the 2nd cut (9 months from transplanting) as influenced by sandy clay soil (SC) or sandy loam soil (SL), and irrigation once/week (I1) or twice/week (I2) with each soil type. Transplants (60 day old) were sown during the season (November). Each result is a mean of 10 replicates ± SE. Statistical analysis was carried out using Duncan. Different letters show significant variation at 0.05 P.

Treatment / Criteria	SC		SL	
	Irrigation/week		Irrigation/week	
	I1	I2	I1	I2
Plant height (cm)	37.48±0.23 d	39.24±0.08 c	45.49±0.11 b	47.6±0.18 a
Mean number of branches/plant	13.5±0.22 d	16.33±0.21 b	16.67±0.21 b	19.67±0.20 a
Mean length of branches/plant (cm)	20.47±0.06 d	33.46±0.22 c	35.12±0.14 b	38.90±0.14 a
Mean length of roots/plant (cm)	16.17±0.06 d	17.57±0.06 c	22.53±0.16 b	23.85±0.19 a
Mean number of roots /plant	9.17±0.31 d	7.08±0.27 c	12.50±0.22 b	14.83±0.48 a
Mean area of leaf (cm ^{2})/ plant	1.13±0.01 d	1.26±0.01 c	1.30±0.01 b	1.72±0.01 a
Root fresh weight (g)	24.29± 0.14 d	25.28± 0.14 c	28.08± 0.07 b	30.73±0.08 a
Shoot fresh weight (g)	51.72±0.39 d	56.37±0.15 c	62.69±0.55 b	70.11±0.61 a
Root dry weight (g)	10.07±0.03 d	11.95±0.10 c	15.29±0.01 b	18.44±0.02 a
Shoot dry weight(g)	19.50±0.02 d	22.64±0.02 c	26.33±0.03 b	33.45±0.06 a

PHOTOSYNTHETIC PIGMENTS

ISSN 2229-5518

Different photosynthetic pigments (chlorophylls a, b and carotenoids) where higher in the leaves of plants grown in the SL soil during the two cuts, as compared with corresponding plants in the SC soil.
The results in Table 5 show that chlorophylls a and b contents (at the 1st and 2nd cuts) were higher in the SL soil and twice irrigation system (I2) than those in case of I1 irrigation, whereas a reverse situation was observed with carotenoids. In case of the SC soil chlorophyll (a& b) contents were higher with I1 irrigation during the 1st cut but the reverse was generally observed at the 2nd cut, where I2 irrigation showed higher enhancement of chlorophylls than I1 irrigation. Despite the irrigation system, the carotenoid content was higher in the SL soil, as compared with the SC soil.

Table 5: Effect of soil type (sandy clay soil (SC) or sandy loam soil (SL)) and irrigation once/week (I1) or twice/week (I2) with each soil type on photosynthetic pigments (mg g $^{-1}$ dwt equivalent) in the leaves of rosemary plants at the 1st and the 2nd cuts (3 and 9 months from transplanting, respectively). Statistical analysis was carried out using Duncan. Different letters show significant variation at 0.05 P.

Treatment		Photosynthetic pigments (mg/g. dwt. equivalent)											
Soil type	Irrigation system	Chl a		Chl b		Chl a/b		Chla+b		Carotenoids		Car/Chls	
		1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
SC	I1	3.86 c ±0.05	7.47 c ±0.02	2.56 b ±0.01	3.18 b ±0.01	1.51 c ±0.02	2.35 a ±0.01	6.43 c ±0.06	10.65 c ±0.03	6.45 c ±0.05	10.49 c ±0.30	1.00 a ±0.01	0.99 b ±0.03
	I2	3.28 d ±0.05	8.20 b ±0.02	2.49 c ±0.02	3.44 a ±0.01	1.32 d ±0.03	2.37 a ±0.01	5.02 d ±0.06	11.63 b ±0.02	4.36 d ±0.02	9.91 d ±0.08	0.87 b ±0.01	0.85 c ±0.00
SL	I1	4.54 b ±0.03	8.22 b ±0.02	2.60 a ±0.01	3.53 a ±0.16	1.73 b ±0.01	2.38 a ±0.08	7.14 b ±0.04	11.72 b ±0.17	7.26 a ±0.01	12.15 a ±0.01	1.02 a ±0.00	1.04 a ±0.01
	I2	5.36 a ±0.01	8.89 a ±0.31	2.62 ab ±0.02	3.56 a ±0.01	2.06 a ±0.02	2.53 a ±0.07	7.98 a ±0.01	12.45 a ±0.32	7.15 b ±0.03	11.79 b ±0.06	0.90 c ±0.01	0.95 b ±0.03
LSD 0.05		0.59	0.67	0.06	0.26	0.19	0.18	0.74	0.73	0.11	0.69	0.10	0.10

YIELD OF ESSENTIAL OIL

At both the 1st and 2nd cuts, the oil content showed highest values in the plants cultivated in the SL soil and I1 irrigation followed by those in similar soil with the I2 irrigation system. In the SC soil the oil content was higher in response to I1 irrigation at both cuts (Table 6). A more or less similar trend was observed with regard to the oil yield/feddan. Table 6 also indicates that either the mean percentage of EO or its yield/feddan were markedly higher at the second cut than the first cut.

Table 6: Oil yield (l/fed) and essential oil percentage (ml/100 g) on a dry weight basis as influenced by cultivation in sandy clay (SC) and sandy loam (SL) soils and irrigation once/week (I1) or twice/week (I2) with each soil type, at the 1st and the 2nd cuts (3 and 9 months from transplanting, respectively). Values expressed are means of three replicates ± SE. Statistical analysis was carried out using Duncan. Different letters show significant variation at 5% level. The mean values of oil productivity at the first cut (February) and the second cut (August) are also shown.

Treatment		Oil percentage (ml/100 g)				Oil yield (l/fed)			
Soil type	Irrigation system	1st cut	Mean	2nd cut	Mean	1st cut	Mean	2nd cut	Mean
SC	I1	0.66±0.01 c	0.66	0.78± 0.00 c	0.82	5.99±0.09 c	6.38	15.92±0.00 c	18.41
	I2	0.49±0.01 d		0.76±0.01 d		4.62±0.00 d		15.75±0.09 c	
SL	I1	0.74±0.01 a		0.88±0.01 a		6.93±0.00 b		18.92±0.09 b	
	I2	0.73±0.00 b		0.86±0.01 b		7.96±0.00 a		23.03±0.23 a	
LSD at 0.05 P		0.013		0.017		0.94		2.99	

Feddan (fed)=4200m²

DISCUSSION

The results obtained showed that the vegetative growth criteria of rosemary at the 1st cut were generally the best in the plants grown in sandy loam (SL) soil and irrigated twice per week (I2), followed by those in similar soil (SL) but irrigated once (I1) per week. A lower performance of plant growth rates was shown in the sandy clay (SC) soilat the 1st cut, where irrigation once was more profitable than twice irrigation per week. At the 2nd cut, the effectiveness of the different treatments on growth could be arranged as follows: SL+I2>SL+I1>SC+I2>SC+I1. These results meant that the increase in irrigation water positively affected the growth of plants grown in sandy soil, but negatively affected rosemary plants grown in the SC soil during the 1st cut (winter). On the other hand, I2 irrigation was more fitting to plant growth, at the 2nd cut (summer), than I1 in both soil types (SL and SC).
Briefly, sandy loam soil combined with irrigation either once (I1) or twice (I2) per week was much better than sandy clay soil in enhancing the growth of rosemary plants expressed as plant height, leaf area, branching and their extension growth, root length, mean number of roots/ plant, as well as the fresh and dry weights of shoots and roots during the two plant cuttings under study. The SL soil in the present work had higher sand (61.5%) and lower clay (8.3%), as compared with the SC soil (39.2% sand and 26.8% clay). Better growth of many plants in sandy soil could be attributed to deeper penetration, spatial distribution and branching of rosemary root, efficiency of nutrition and free movement of water through the soil particles as a result of the porous property of the SL soil type [20, 21, 22]. Enhancement of growth was also recorded in sandy soil with *Hibiscus sabdariffa* [11]. *Centella asiatica* grown in sandy loam (60% sand) habitat also grew better rather than in clayey soil approximately devoid of sand [10]. These conclusions were in alliance with our results which showed increased root length and number of roots in rosemary plants grown in SL soil, as compared to those grown in SC soil, despite of the irrigation system. The significance of root growth could be further reinforced by the results of Bahreininejad et al. [23], who revealed reduced fresh and dry weights of

Thymus daenensis under water stress, but these criteria became significantly higher in the second year when plants produced deeper roots.

In the present study, supplying SC soil with I2 irrigation system led to a decrease of the different growth parameters of rosemary plants at the first cut, compared to corresponding values in the plants subjected to I1 irrigation system. This result might be interpreted on the bases that at the first cut during winter (February), the water content (SWC=83.7%) was at a surplus, whereas at the second cut during summer (August), irrigation in the SC soil through the I2 system allowed a suitable moisture content (SWC=71.17%). This could be assumed to excess water in such a non-porous soil with poor aeration, that would then be predicted to limit aeration, reduce oxygen supply to the roots, and consequently retards respiration, nutrient uptake and other critical root functions [24, 25]. Reduced total root volume would then affect shoot growth, photosynthesis, and other metabolic processes of the plant [26]. However, the requirements for optimum growth and yield differ from a plant to another. For example, in oregano, the optimum irrigation levels for the highest yields of fresh herb and essential oil was 80% available soil moisture [27[. But, a reverse conclusion was obtained by Metwally et al. [7] who found thatw water regimes of 75% field water capacity was concomitant with increased growth and flowering criteria of *Calendula officinalis* plants.

The results of the present work also showed a markedly increased branching that underlined the increase in fresh and dry weights of shoots of these plants at the second cut. However, the difference in the mean values of growth parameters at the two cuttings might result from varying climatic factors as temperature and humidity [12] as well as soil conditionsas mentioned above. Similar conclusions were recorded in *Artemisia annua* [28, 29].

Despite the irrigation system, the carotenoid content was higher in the SL soil, as compared with the SC soil. This might be attributed to the soil water content. This conclusion could be supported by that of Ahmad et al. [30] where the carotenoid content was increasing progressively with the increase in drought. In such cases, the increase in the carotenoid content of leaves could contribute to prevent chlorophyll degradation and photo damage in rosemary plants [31]. In addition, drought stress led to increase the carotenoid content in two maize cultivars [32] and two poplar genotype [33].

In the present study, total chlorophylls were generally positively correlated with the dry matter accumulation of the differently treated plants. Water deficit led to a decrease of chlorophylls a, b, and total chlorophylls [34, 35] and this could directly affect plant biomass production [36] througha affecting the photosynthetic rate [34, 37]. Reduction in dry matter as a result of reduced chlorophyll content under water deficit was reported in rosemary [8] and two sugarcane varieties [38].

In the present work, the increase of dry weights of the differently treated plants were in alliance with the increase in Chl a/b ratios at the first cut whereas there was no significant variation in this ratio within the different treated plants at the second cut.A At the first cut, where the growth of roots was rather limited, chlorophyll a/b ratio was in the SL soil significantly lower in case of the I1t than in the I2 irrigation system which might suggest the tolerance of rosemary to water restriction. According to Chakraborty et al. [39] a lower chlorophyll a/b ratio was obtained in tolerant than in susceptible peanut cultivars, due to lesser damage to PSI and PSII, leading to better capacity to photosynthesize even under stressed condition. In two drought-stressed cotton (*Gossypium hirsutum*) genotypes Chl a/b ratiosw were alsod decreased [40].

Our results showed that the essential oil (EO) content (%) and oil yield((l/fed) of rosemary varied with different types of soil (SC and SL) and irrigation water contents (I1 or I2) throughout the duration of the experiment (9 months). The results obtained showed that the oil yield was generally higher at the second cut (August), compared to that during the first cut (February). At the second cut, a 188.6 % increase was obtained in the mean value of EO (for all treatments), compared to that during the first cut (February). This might be attributed to either the climatic conditions or the plant age or both. In this respect, Miguel et al. [41] showed that best results were obtained in August, where the yield and the chemical composition of rosemary oils seemed to be more sensitive to the temperature, photoperiod and collection period. The yield of essential oils of two species of Ocimum *Ocimum* was also affected by the environmental conditions [42]. Such conditions cause biochemical and physiological alterations in plants and thus modify the quantity and quality of essential oils [43, 44].

The results of the present work also indicated that the yield of EO (l/fed) of rosemary was higher in SL soil combined with I1 and I2 irrigation (25.85 and 30.99 l/fed, respectively), compared to those of corresponding plants grown in the SCsoil and similarly supplied with I1 and I2 irrigation systems (21.91 and 20.37l/fed, respectively) during the two applied cuttings (Table 6). In this connection, essential oil content (ml/plant) and essential oil yield (l/fed) of *Artemisia Annua* L. were variably affected by soil types [29].

The oil yield (l/fed) was significantly increased with increasing soil water content (SWC) in the SL soil. Sandy loam soil combined with I2 irrigation (SWC= 76.03, 61.75% at the1st and 2nd cuts, respectively) increased oil yield (l/fed) to 72.29 and 46.22% more than the plants grown in the SC soil and supplied with I2((SWC= 83.70, 71.17% at the 1st and 2nd cuts, respectively). In this connection, Hassan et al. [8] found that the volatile oil percentage of rosemary plants was progressively increased by decreasing the level of deficit irrigation. The highest percentage was obtained by irrigation at 60% field capacity. In other studies, water stress also had positive effects on essential oil content of *Pimpinella anisum* ([45], *Salvia officinalis* [46], and *Ocimum basilicum* [47, 48, 12].

CONCLUSION

We found that interaction between soil types, water content and harvest time were important management factors to control the growth and essential oil productivity of rosemary plants. At the second cut (August), most growth criteria and EO content (%) and yield (l/fed) of rosemary plants were markedly improved in different soil types (SC or SL) and irrigation courses (I1 or I2) with each soil type), compared to those at the 1st cut (February). In this respect, best results were obtained with SL soil + I2 irrigation. But, under SC soil conditions, I1 irrigation (to avoid water depletion) should be an appropriate choice for the first growing season (1st cut) and I2 irrigation for the second growing season (2nd cut) to gain an improved herb fresh yield and essential oil production. Generally, rosemary can maximize growth and oil yield in habitat with SL type of soil combined with I2 irrigation rather than SC soil during the two cuttings. The growth rates and EO yield of rosemary plant were consistent with corresponding changes in photosynthetic pigments.

REFERENCES

[1] G. Pintore, M. Usai, P. Bradesi, C. Juliano, G. Boatto, F. Tomi, M. Chessa, R. Cerri, and J. Casanova, "Chemical composition and antimicrobial activity of *Rosmarinus officinalis* L. oils from Sardinia and Corsica". Flav Frag J. 7: 15-19, 2002.

[2] N.V. Yanishlieva, E. Marinova, and J. Pokorny, "Natural antioxidants from herbs and spices". European J Lipid Sci Technol. 108 (9): 776–793, 2006.

[3] S. Moreno, T. Scheyer, C.S. Romano, and A.A. Vojnov, "Antioxidant and antimicrobial activities of rosemary extracts linked to their polyphenol composition". Free Radical Res. 40: 223–231, 2006.

[4] T. Atsumi, and K. Tonosaki, "Smelling lavender and rosemary increases free radical scavenging activity and decreases cortisol level in saliva". Psychiatry Res. 150 (1): 89–96, 2007.

[5] B. Ali, N.A. Al-Wabel, S. Shams, A. Ahamad, S.A. Khan, and F. Anwar, "Essential oils used in aromatherapy: A systemic review". Asian Pacific J Trop Biomed. 5 (8): 601- 611, 2015.

[6] E. Nicolaś, T. Ferrandez, J.S. Rubio, J.J. Alarcoń, and M. Sańchez-Blanco, "Annual water status, development, and flowering patterns for *Rosmarinus officinalis* plants under different irrigation conditions". Hort. Sci. 43 (5): 1580-1585, 2008.

[7] M. Singh, and S. Ramesh, "Effect of irrigation and nitrogen on herbage, oil yield and water-use efficiency in rosemary grown under semi-arid tropical conditions". J Med Arom Plant Sci. 22 (IB): 659–662, 2000.

[8] F.A.S. Hassan, S. Bazaid, and E.F. Ali, "Effect of deficit irrigation on growth, yield and volatile oil content on *Rosmarinus officinalis* L". Plant J Med Plant Stud. 1 (3): 12-21, 2013.

[9] B.H. Abou-Leila, M.S. Hussein, and S.E. El-Sherbeny, "A comparative study on growth, yield and chemical composition of *Datura metel* L. grown in different soil types". Egypt. J. physiol. Sci., 17: 323-333, 1993.

[10] A. Devkota, and P.K. Jha, "Variation in growth of *Centella asiatica* along different soil composition". Bot Res Int. 2 (1): 55-60, 2009.

[11] S.E. Khalil, and A.A.S. Abdel-Kader, "The influence of soil moisture stress on growth, water relation and fruit quality of *Hibisicus sabdariffa* L. grown within different soil types". Nature and Science. 9(4): 62-74, 2011.

[12] S. Ekren, C. Sonmez, E. Ozcaka, Y.S.K. Kurttas, E. Bayram, and H. Gurgulu, "The effect of different irrigation water levels on yield and quality characteristics of purple basil (*Ocimum basilicum* L.)". Agric Water Manag. 109: 155–161, 2012.

[13] M. Sarani, M. Namrudi, S.M. Hashemi, and M.M. Raoofi, "The effect of drought stress on chlorophyll content, root growth, glucosinolate and proline in crop plants". Int J Farming Allied Sci. 3 (9): 994-997, 2014.

[14] R.O. Okwany, T.R. Peters, K.L. Ringer, D.B. Walsh, and M. Rubio, "Impact of sustained deficit irrigation on spearmint (*Mentha spicata* L.) biomass production, oil yield, and oil quality". Irrig Sci. 30 (3): 213:– 219, 2012.

[15] S.J. Zwart, and W.G.M. Bastiaanssen, "Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize". Agric Water Manag. 69(2): 115- 133, 2004.

[16] E. Fereres, and M.A. Soriano, "Deficit irrigation for reducing agricultural water use". J Exp Bot. 58 (2): 147-159, 2007.

[17] S.A. Metwally, K.A. Khalid, and B.H. Abou-Leila, "Effect of water regime on the growth, flower yield, essential oil and proline contents of *Calendula officinalis*". Natural Biosci. 5 (2): 65-69, 2013.

[18] A. Cottenie, M. Verloo, L. Kiekens, G. Velghe, and R.C Camerlynck, "Chemical Analysis of Plant and Soil Laboratory of Analytical and Agrochemistry". State University Ghent, Belgium. Pp: 100-129, 1982.

[19] H. Metzener, H. Rauand, and H. Senger, "Unter suchungen zur synchronisier barteit einzelner pigmentan angel mutanten von *Chlorella*". Planta. 65: 186, 1965.

[20] U. Burman, M.D. Bohra, L.N. Harsh, and J.C. Tiwari, "Water relation and growth of *Simmondsia chinensis* and *Prasopis juliflord* seedlings at nursery stage". Indian Forester. 127: 351-357, 2001.

[21] A.A.M. Mazhar, N.G. Abd- El Aziz, and E. El Habba, "Impact of different soil media on growth and chemical constituents of *Jatropha curcas* L. seedlings grown under water regime". J. Amer. Sci. 6: 549-556, 2010.

[22] S.E. Khalil, and R.M.M. Yousef, "Study the effect of irrigation water regime and fertilizers on growth, yield and some fruit quality of *Hibiscus sabdariffa* L." Int J Adv Res. 2(5): 738-750, 2014.

[23] B. Bahreininejad, J. Razmjoo, and M. Mirza, "Influence of water stress on morpho-physiological flowering and some yield traits of coriander and phytochemical traits in *Thymus daenensis*". Int. J Plant Produc. 7(1): 151-165, 2013.

[24] A. R. Dexter, "Soil physical quality: Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth". Geoderma. 120 (3–4): 201–214, 2004.

[25] A. Pierret, C. Doussan, Y. Capowiez, F. Bastardie, and L. Pagès, "Root functional architecture: A framework for modeling the interplay between roots and soil". Vadose Zone J. 6(2): 269-281, 2007.

[26] U. Najeeb, M.P. Bange, D.K.Y. Tan, and B.J. Atwell, "Consequences of water logging in cotton and opportunities for mitigation of yield losses". AoB Plants PLANTS. 7: 1-17, 2015.

[27] H.A.H. Said-Al Ahl, E.A. Omer, and N.Y. Naguib, "Effect of water stress and nitrogen fertilizer on herb and essential oil of oregano". Int. Agrophys. 23: 269-275, 2009.

[28] R. Baraldi, B. Isacchi, S. Predieri, G. Marconi, F.F. Vincieri, and A.R. Bilia, "Distribution of Artemisinin and bioactive flavonoids from *Artemisia annua* L. during plant growth". Bioch Syst Ecol. 36: 340-348, 2008.

[29] E.A. Omer, E.A. Abou Hussein, S.F. Hendawy, A.A. Ezz El-din, and A.G. El-Gendy, "Effect of soil type and seasonal variation on growth, yield, essential oil and artemisinin content of *Artemisia annua* L". Int Res J Hort. 1(1): 15-27, 2013.

[30] M.A. Ahmad, P.V. Murali, and R. Panneerselvam, "Drought stress induced biochemical alterations in two varieties of *Paspalum scrobiculatum* L". Int. J. Curr. Sci. 7: 80-96, 2013.

[31] S. Munné-Bosch, and J. Peñuelas, "Photo- and antioxidative protection during summer leaf senescence in *Pistacia lentiscus* L. grown under Mediterranean field conditions". Ann. Bot. 92: 385.-391, 2003.

[32] N. Mohammadkhani, and R. Heidari, "Effects of Water Stress on Respiration, Photosynthetic Pigments and Water Content in Two Maize Cultivars". Pakistan J Biol Sci. 10: 4022-4028, 2007.

[33] X. Xiao, X. Xu, and F. Yang, "Adaptive responses to progressive drought stress in two *Populus cathayana* populations". Silva Fennica. 42(5): 705–719, 2008.

[34] K.K. Surendar, D.D. Devi, I. Ravi, P. Jeyakumar, and K. Velayudham, "Water stress affects plant relative water content, soluble protein, total chlorophyll content and yield of Ratoon Banana". Int J Hort. 3(17): 96-103, 2013.

[35] F. Shekari, V. Soltaniband, A. Javanmard, and A. Abbasi, "The impact of drought stress at different stages of development on water relations, stomatal density and quality changes of rapeseed (*Brassica napus* L.)". Iran Agric Res. 34(2) 81-90, 2015.

[36] S.M. Zingaretti, M.C. Inácio, L.d.M. Pereira, T.A. Paz, and S.D.C. Franca, "Water Stress and Agriculture, Responses of Organisms to Water Stress", Dr. Sener Akinci (Ed.), In Tech, DOI: 10.5772/53877. http://www.intechopen.com/books/responses-of-organisms-to-water-stress/water-stress-and-agriculture. 2013.

[37] M. Al Hassan, M.M. Fuertes, F.J.R. Sánchez, O. Vicente, and M. Boscaiu, "Effects of salt and water stress on plant growth and on accumulation of osmolytes and antioxidant compounds in cherry tomato". Notulae Botanicae Horti Agrobotanici. 43: 1-11, 2015.

[38] D.B. Medeiros, E.C. da Silva, R.J.M.C. Nogueira, M.M. Teixeira, and M.S. Buckeridge, "Physiological limitations in two sugarcane varieties under water suppression and after recovering". Theor Exp Plant Physiol. 25(3): 213-222, 2013.

[39] K. Chakraborty, A.L. Singh, K.A. Kalariya, N. Goswami, and P.V. Zala, "Physiological responses of peanut (*Arachis hypogaea* L.) cultivars to water deficit stress: status of oxidative stress and antioxidant enzyme activities". Acta Bot Croat. 74 (1): 123–142, 2015.

[40] A.K. Parida, V.S. Dagaonkar, M.S. Phalak, G.V. Umalkar, and L.P. Aurangabadkar, "Alterations in photosynthetic pigments, protein and osmotic components in cotton genotypes subjected to short-term drought stress followed by recovery". Plant Biotech Rep.1: 37–48, 2007.

[41] M.G. Miguel, C. Guerrero, H. Rodrigues, and J. Brito, "Essential oils of *Rosmarinus officinalis* L., effect of harvesting dates, growing media and fertilizers". In: Proceedings of the 3rd IASME/WSEAS International Conference on Energy, Environment, Ecosystems and Sustainable Development, Agios Nikolaos, Greece, July. Pp: 24–26, 2007.

[42] K.A. Khalid, "Influence of water stress on growth, essential oil and chemical composition of herbs (*Ocimum* sp.)". Int. Agrophys. 20 (4): 289-296, 2006.

[43] N.S. Sangwan, A.H.A. Farooqi, F. Shabih, and R.S. Sangwan, "Regulation of essential oil production in plants". Plant Growth Regu. 34: 03–21, 2001.

[44] C.L. Prins, I.J.C. Vieira, and S.P. Freitas, "Growth regulators and essential oil production". Brazilian J Plant Physiol. 22(2): 91-102, 2010.

[45] S. Zehtab-Salmasi, A. Javanshir, R. Omidbaigi, H. Aly-Ari, and K. Ghassemi-Golezani, "Effects of water supply and sowing date on performance and essential oil production of anise (*Pimpinella anisum* L.)". Acta Agron Hung. 49 (1): 75–81, 2001.

[46] I. Bettaieb, N. Zakhama, W.A. Wannes, M.E. Kchouk, and B. Marzouk. "Water deficit effects on *Salvia officinalis* fatty acids and essential oils composition". Scien Hort. 120: 271–275, 2009.

[47] R. Omidbaigi, A. Hassani, and F. Sefidkon, "Essential oil content and composition of sweet basil (*Ocimum basilicum*) at different irrigation regimes". J Es-

sential Oil. 6(2): 104-108, 2003.
[48] A.H. Moeini, R. Heidari, A. Hassani, and A.A. Dizaji, "Effect of water stress on some morphological and biochemical characteristics of purple basil (*Ocimum basilicum*)". J Biol Sci. 6(4): 763-767, 2006.