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Effect of Soil Type and Irrigation Intervals on Plant Growth, Essential Oil Yield and Constituents of *Thymus vulgaris* Plant

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Abstract: The environmental stresses are major limiting factors in crop production because, they affect almost all plant functions. The content of the essential oil and its composition in thyme depend on different factors. Therefore, this investigation aimed to study the effect of soil type (sand, clay loam and calcareous soil) and/or irrigation intervals (3, 5, 7 and 10 days) on plant growth, essential oil yield and its main constituents of *Thymus vulgaris* plant. Plants grown in calcareous soil recorded the highest values for plant height, fresh and dry weight of herb per plant followed by clay loam, then sandy soil. Plants received irrigation every 3 days recorded significant increase in plant height, fresh and dry weight of herb per plant as compared with plants irrigated every 5, 7 and 10 days. Generally, increasing the period between irrigation (every 10 days) gave the lowest values for parameters. The plant grown in calcareous soil and irrigated every 3 days showed the highest values for plant growth. Plant irrigated every 10 days gave the highest relative percentage of thymol, which reached 71.32, 50.68 and 47.71% in sandy, calcareous and clay loam soil, respectively. This effect was accompanied with decrease in ρ-cymene content. The rate of transformation of ρ-cymene to phenolic compound thymol is higher under stress conditions.

Key words: *Thymus vulgaris* · Essential oil · Water stress · Soil type · Medicinal · Aromatic plants

INTRODUCTION

Thyme (*Thymus vulgaris* L.) belongs to the Lamiaceae family, is pleasant smelling perennial shrub, which grows in several regions in the world [1]. Thyme is native to the Western Mediterranean region and Southern Italy. As a valuable medicinal plant *Thymus vulgaris* possesses antispasmodic, antiseptic, expectorant, carminative, antitussive and antioxidative properties [2]. The main constituents of thyme include thymol, carvacrol and flavonoids often thought to have antibacterial, anti-flatulent and anti-worm properties [3,4]. Thymol has antifungal activity in number of species including *Cryptococcus neoformans*, *Aspergillus*, *Sapralenia* and *Zygorohynchus*. Further studies confirm the antibacterial properties with demonstrated activity against *Salmonella typhimurium, Staphyllococcus aureus* and *Escherichia coli* [5].

Characteristic compounds of *T. vulgaris* essential oil have been established, namely: Thymol (44.4-58.1%). ρ-cymene (9.1-28.5%), γ-terpinene (6.9-18.9%) and carvacrol (2.4-4.2%) [6].

Several factors may affect the levels of the active principles of plant material. Biotic and abiotic stresses exert a considerable influence on the levels of secondary metabolites in plants [7]. Sharma and Kumar [8] who stated that the incense in irrigation frequency resulted in greater leaf area index and branches/plant of mustard. Ali [9] stated that the best irrigation water quantity treatment for enhancing growth and alkaloid yield of *Hyoscyamus muticus* was that application of 1200 m3 water per fed. Under drip irrigation system in North Sinai conditions. Mahmoud [10] showed that water supply every 6 or 8 day intervals caused dramatically decrease in the plant growth, flower yield and the resin content of *Grindelia camportum* Green. However, the effect of irrigation repeated in every 4 days seemed to be optimal and produced the highest production of fresh and dry biomass. It is possible to increase the content of pharmacologically desirable compounds by manipulating

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agricultural techniques such as irrigation or using photobioreactor systems [2]. Plant secondary metabolism and its metabolites result from the response and adaptation to different environmental stresses during the long process of evolution and hence the production of secondary metabolites closely relate to environmental factors including biotic and a biotic factors [11].

The content of the essential oil and its composition in thyme depend on different factors, cultivation conditions such as climate, geographic origin, harvesting time and use of fertilizers. Therefore this study aimed to evaluate the effect of soil type and irrigation intervals on plant growth, essential oil yield and its main constituents of *Thymus vulgaris* plant.

MATERIALS AND METHODS

This investigation was carried out at a greenhouse experiment in the National Research Centre, Dokki, Cairo, Egypt for two consecutive years, 2005 and 2006. The aim of this study was to elucidate the effect of soil type and irrigation intervals on plant growth, essential oil yield and its main constituents of *Thymus vulgaris* plant.

The layout of the experiment was factorial arrangement of all combinations between soil type (sand, clay loam and calcareous soil) and irrigation intervals (3, 5, 7 and 10 days), one liter of water was applied per one pot. Each treatment was replicated three times.

On 15th February, healthy, 45 day old seedlings of *Thymus vulgaris*, (small shoots with roots) were transplanted (one seedling /pot) into clay pots (30 cm in diameter) filled with 12 kg of the used soil. Sand and calcareous soils were collected from East Nobaria. While clay loam soil was collected form Giza farm. The physical and chemical characteristics of the used soil were determined according to Bremner and Mulvaney [12] and presented in Table 1.

All treatments received basal fertilizers of ammonium nitrate (33.5% N), calcium super phosphate (15% P_2O_2) and potassium sulphate (48% K_2O) at ratio of 2:2:2. The quantities of NPK (6 gm/pot) were added twice, the first, after one month from seedling and the second one month later. The plants were harvested two times (in June and October) during the two successive seasons. At each harvesting time, plant height, fresh and dry weights of herb per plant were recorded. The obtained data were statistically analyzed according to Snedecor and Cochran [13], using L.S.D. at the level of 5%.

Samples from the fresh herb of each treatment were separately subjected to hydro-distillation in order to determine the percentage of essential oil (V/W) according to the Egyptian Pharmacopoeia [14].

The essential oil resulted from each treatment was dehydrated over anhydrous sodium.

GLC analysis of volatile oil of each treatment was performed separately with a Hewlett-Packard model 5890. A fused silica capillary column carbowax 20 M measuring 25 m x 0.32 mm internal diameter, film thickness of 0.17 µm. The temperature program adopted was maintained at 75°C for 5 min with an increase of 4°C /min until 220°C (10 min); mass spectra were recorded. The carrier gas was helium and the working flow rate was 1.0 ml/min, detector was 9144 HP. Compounds were identified by matching of their mass spectra with those recorded in the MS Library and

Table 1: Soil analysis

Physical properties

Soil texture	Soil fraction: Sand	Silt	Clay	$CaCO_3$ %
Sandy	90.3	8.6	1.1	8.5
Loamy sand (calcareous)	82.0	18.0	0.0	30.6
Clay loam	23.0	46.0	31.0	5.2

Chemical properties

	pH	EC (dS/m)	Soluble cations meq/l: Na^+	Ca^{2+}	Mg^{2+}	K^+
Sandy	8.4	0.68	4.9	1.15	0.40	0.10
Loamy sand (calcareous)	8.5	2.10	12.0	5.10	2.80	0.15
Clay loam	7.6	1.72	7.20	4.50	4.80	0.24

	Soluble Anions meq/l: Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-
Sandy	1.85	3.36	-	1.40
Loamy sand (calcareous)	15.50	0.97	-	3.53
Clay loam	6.30	6.20	-	4.30

further confirmed by comparison of the mass spectra with those of reference compounds or with published data. The identification of these compounds was achieved by matching their retention times with those of authentic samples injected under the same conditions.

RESULTS AND DISCUSSION

Plant Growth: The obtained results (Table 2 and 3) showed that soil type and irrigation intervals had a significant effect on plant growth, i. e. plant height, fresh and dry weight of herb during the two seasons. In the first cut at the first season, the plants grown in calcareous soil recorded the highest values for plant height (26.08 cm), fresh and dry weight (71.40 and 28.18 gm/plant) followed by clay loam soil, then sandy soil. i.e. it had favorable effect on the whole parameters of the vegetative growth and this hold for both cuts in the two investigated seasons.

Concerning, the effect of irrigation intervals, it was found that plant height, fresh and dry weight of herb varied significantly under different irrigation intervals and decreased significantly with increasing the period between irrigation from 3 to 5, 7 and 10 days in the first and second cut during the two seasons. In the first cut at the first season, irrigation intervals every 5 days exhibited 10.92, 9.78 and 9.47% reduction in plant height, fresh and dry weight, respectively. But with irrigation every 7 days, the reduction was 22.20, 21.86 and 16.69%, respectively. And more reduction i.e.25.70, 48.07 and 32.91% was obtained with increasing the period between irrigation to 10 days. The same observation was obtained in the second season. Generally, the thyme plant grown in calcareous soil and irrigated every 3 days resulted in the highest production. This effect might be due to water stress, which is characterized by reduction of water content, turgor, total water potential, wilting, closure of stomata and decrease in cell enlargement and growth. The quantity and quality of plant growth depend on cell division, enlargement and differentiation and all of these events are affected by water stress [15]. These results agreed with that reported by Sharma and Kumar [8], who stated that the incense in irrigation frequency resulted in greater leaf area index and branches/plant of mustard. Ali [9] stated that, the best irrigation water quantity treatment for enhancing growth and alkaloid yield of *Hyoscyamus muticus* was that application of 1200 m3 water per fed. Under drip irrigation system under North Sinai conditions. Mahmoud [10] showed that water supply every 6 or 8 day intervals caused dramatically

Table 2: Effect of soil type and irrigation intervals on plant growth of *Thymus vulgaris* L during 2005 season

	Plant height (cm)		Fresh weight (g/plant)		Dry weight (g/plant)	
Treatment	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
(a) soil type						
Sand	21.83	22.07	58.09	54.94	25.83	22.47
Clay loam	25.17	24.84	67.31	68.74	27.47	26.86
Calcareous	26.08	27.52	71.40	83.58	28.18	33.68
L.S.D. at5%	0.45	0.33	2.98	0.56	0.58	0.43
(b)Irrigation intervals(Days)						
3	28.56	30.91	81.93	107.50	31.87	36.46
5	25.44	24.60	73.91	84.98	28.85	30.73
7	22.22	22.87	64.02	54.62	26.55	23.70
10	21.22	20.50	42.55	31.91	21.38	19.80
L.S.D. at5%	0.52	0.38	3.44	0.65	0.67	0.50
(c)Interaction between soil type and Irrigation intervals						
Sand						
3	25.67	27.68	70.37	100.59	29.68	32.90
5	21.67	21.75	69.52	58.91	27.40	23.19
7	20.67	20.33	54.63	50.57	26.58	18.59
10	19.33	18.53	37.85	17.71	19.69	15.20
Clay loam						
3	28.33	30.38	83.49	105.62	32.80	33.77
5	25.67	24.65	73.40	91.31	28.72	30.38
7	22.33	23.68	65.64	50.42	24.61	23.65
10	24.33	20.64	46.73	27.61	23.75	19.64
Calcareous						
3	31.67	34.68	91.92	116.30	33.18	42.71
5	29.00	28.48	78.81	104.73	30.42	38.62
7	23.67	24.61	71.82	62.89	28.44	28.68
10	20.00	22.32	43.07	50.42	20.69	24.55
L.S.D. at5%	0.90	0.65	5.95	1.12	1.17	0.86

Table 3: Effect of soil type and irrigation intervals on plant growth of *Thymus vulgaris* L. during 2006 season

	Plant height (cm)		Fresh weight (g/plant)		Dry weight (g/plant)	
Treatment	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
(a) soil type						
Sand	21.50	23.08	61.20	68.41	26.59	30.84
Clay loam	26.33	27.91	65.69	71.39	29.65	31.62
Calcareous	27.17	29.27	71.73	84.92	33.04	38.76
L.S.D. at5%	1.29	1.12	3.04	2.02	0.96	1.39
(b)Irrigation intervals(Days)						
3	30.56	31.67	81.61	109.38	35.61	43.13
5	26.22	28.67	73.36	86.20	32.20	36.45
7	21.67	23.57	64.88	60.36	26.63	29.77
10	21.56	22.67	44.99	43.69	24.59	25.62
L.S.D. at5%	1.49	1.29	3.50	2.33	1.11	1.60
(c)Interaction between soil type and Irrigation intervals						
Sand						
3	26.00	27.33	75.90	103.51	32.08	39.50
5	22.00	23.67	70.37	66.21	29.73	34.94
7	19.00	21.00	58.18	59.13	24.17	27.47
10	19.00	20.33	40.36	44.78	20.37	21.49
Clay loam						
3	31.33	32.00	78.80	108.92	35.01	37.91
5	26.67	30.00	69.03	87.47	31.95	33.12
7	22.67	25.33	62.89	56.94	25.65	28.50
10	24.67	24.33	52.03	32.25	25.98	26.96
Calcareous						
3	34.33	35.67	90.12	115.72	39.74	51.99
5	30.00	32.33	80.67	104.93	34.91	41.28
7	23.33	25.33	73.56	65.01	30.40	33.34
10	21.00	23.33	42.58	54.03	27.42	28.42
L.S.D. at5%	2.59	2.23	6.08	4.04	1.92	2.77

Table 4: Effect of soil types and irrigation intervals on the essential oil contents of *Thymus vulgaris* L.plant during 2005 season

	Oil%		Oil yield ml/plant	
Treatment	1st cut	2nd cut	1st cut	2nd cut
(a) soil type				
Sand	0.30	0.32	0.18	0.20
Clay loam	0.33	0.34	0.21	0.22
Calcareous	0.34	0.36	0.24	0.30
L.S.D. at5%	0.01	0.01	0.01	0.01
(b)Irrigation intervals(Days)				
3	0.30	0.32	0.24	0.35
5	0.34	0.36	0.25	0.30
7	0.33	0.34	0.21	0.18
10	0.32	0.33	0.14	0.12
L.S.D. at5%	0.01	0.01	0.01	0.01
(c)Interaction between soil type and Irrigation intervals				
Sand				
3	0.32	0.36	0.23	0.36
5	0.39	0.40	0.27	0.24
7	0.30	0.33	0.16	0.17
10	0.18	0.20	0.07	0.04
Clay loam				
3	0.26	0.27	0.21	0.29
5	0.32	0.31	0.23	0.28
7	0.35	0.37	0.23	0.19
10	0.38	0.39	0.18	0.11
Calcareous				
3	0.31	0.35	0.28	0.41
5	0.32	0.36	0.25	0.37
7	0.35	0.31	0.25	0.20
10	0.40	0.40	0.17	0.20
L.S.D. at5%	0.01	0.01	0.02	0.01

Table 5: Effect of soil types and irrigation intervals on the essential oil contents of *Thymus vulgaris* Lplant during 2006 season

	Oil%		Oil yield ml/plant	
Treatment	1st cut	2nd cut	1st cut	2nd cut
(a) soil type				
Sand	0.31	0.33	0.20	0.23
Clay loam	0.34	0.35	0.22	0.24
Calcareous	0.36	0.39	0.25	0.33
L.S.D. at 5%	0.01	0.01	0.01	0.01
(b)Irrigation intervals(Days)				
3	0.31	0.34	0.25	0.37
5	0.35	0.37	0.26	0.31
7	0.35	0.36	0.23	0.22
10	0.33	0.35	0.15	0.15
L.S.D. at 5%	0.01	0.01	0.01	0.01
(c)Interaction between soil type and Irrigation intervals				
Sand				
3	0.33	0.36	0.25	0.37
5	0.39	0.39	0.27	0.26
7	0.32	0.34	0.19	0.20
10	0.19	0.24	0.08	0.11
Clay loam				
3	0.28	0.30	0.22	0.33
5	0.33	0.35	0.23	0.30
7	0.37	0.36	0.23	0.20
10	0.38	0.37	0.20	0.12
Calcareous				
3	0.32	0.36	0.29	0.42
5	0.34	0.38	0.27	0.40
7	0.36	0.39	0.26	0.25
10	0.42	0.43	0.18	0.23
L.S.D. at5%	0.02	0.02	0.02	0.02

decrease in the plant growth, flower yield and the resin content of *Grindelia camportum* Green. However, the effect of irrigation repeated in every 4 days seemed to be optimal and produced the highest production of fresh and dry biomass. Also, the reduction in leaf area by water stress was an important cause of reduced crop yield through reduction photosynthesis [16].

Essential Oil Percentage and Yield in Thyme Plants: The results showed that soil types and irrigation intervals had effects on the percentage and yield of thyme essential oil during the two seasons (Table 4 and 5). The highest essential oil percentage and yield in the 1st cut and 2nd cut at the first season were determined from plant grown in calcareous soil, followed by that in clay loam and then sandy soil. Concerning, the effect of irrigation intervals, In the first season, it was found that, the highest essential oil percentage (0.34 and 0.36% in the 1st cut and 2nd cut, respectively) were obtained from plant irrigated every 5 days. While the essential oil yield decreased with increasing the period between irrigation and giving the lowest values (0.14 and 0.12 ml/pant in the 1st cut and 2nd cut, respectively) from plants irrigated every 10 days. Generally, in the first season, the greatest essential oil percentage (0.40 and 0.40% in the 1cut and 2 cut, respectively) were obtained from plants grown in calcareous soil and irrigated every 10 days. On the contrary the essential oil yields (ml / plant) decreased with increasing the irrigation period (every 10 days) resulted in the lowest values. This effect due to drought stress is one of the major causes for crop loss worldwide, reducing average yields with 50% and over [17]. Thus, increasing the level of the soluble salts in the soil solution tends to increase its osmotic pressure and/or cause an individual ion toxicity, which leads to decrease in the water and nutrient uptake by plants, caused induction of PEP carbxylase activity and essential oil biosynthesis [18]. Under such stress, water deficit in plant tissue develops, thus leading to significant inhibition of photosynthesis. Then Plant reacts to water deficit with a rapid closure of stomata to avoid further water loss via transpiration. As a consequence, CO_2 diffusion into the leaf is restricted which results in limitation of photosynthesis at the acceptor site of ribulose-1,5 biphosphate carboxylase/oxegenase [19] or by the direct inhibition of photosynthetic enzymes like (Rubisco)[20] or ATP synthesis [21].

Essential Oil Composition: The results in Table 6 showed that variable effects ascending or descending

Table 6: Effect of soil type and irrigation intervals on essential oil composition of *Thymus vulgaris* L. plant

	3 day			5 day			7 days			10 days		
Oil composition	Sandy	Clay loam	Calcareous	Sandy	Clay loam	Calcareous	Sandy	Clay loam	Calcareous	Sandy	Clay loam	Calcareous
α-pinene	2.62	2.13	2.78	2.96	2.74	3.46	2.23	1.81	2.83	2.06	2.39	1.61
Myrecen	3.25	2.74	3.59	3.20	3.48	3.91	3.15	2.74	3.28	3.12	2.84	2.94
ρ-cymene	34.93	34.60	24.62	32.13	32.77	33.36	30.84	27.55	32.65	3.72	26.29	26.78
γ-terpinene	2.88	1.52	3.23	2.47	4.12	5.70	2.73	5.39	4.64	1.36	1.98	2.71
Linalool	2.81	2.43	2.74	2.78	2.38	0.15	2.60	3.03	2.34	5.98	4.38	2.13
Comphor	0.41	0.40	0.56	0.43	0.53	2.64	0.40	0.55	0.33	1.09	1.01	0.39
Boroneol	3.92	4.08	4.35	4.34	4.13	3.59	3.52	4.08	4.01	2.08	5.84	4.0
Terpineol	2.26	1.95	1.89	2.05	1.64	2.54	3.24	1.63	2.47	0.59	0.60	1.81
Thymol	39.49	43.30	47.87	44.24	42.15	39.67	44.20	45.94	40.35	71.32	47.71	50.68
Carvacrol	1.00	1.04	1.15	0.85	0.21	0.15	0.24	0.18	0.22	2.10	0.23	0.09
β-bourbonene	0.46	0.39	0.23	0.36	0.04	0.04	0.02	0.03	0.04	-	0.07	0.03
Trans-caryophllene	1.94	0.64	0.57	0.50	-	0.39	0.23	0.32	0.47	0.70	0.60	0.34
α-Hemulene	0.34	1.41	1.29	1.33	-	-	-	-	-	2.74	1.58	1.56
Cadinene	0.87	0.73	0.27	0.31	1.80	1.12	2.12	2.09	1.97	0.52	0.37	0.46
GermacreneD	0.42	0.21	0.75	0.65	0.26	0.24	0.32	0.34	0.77	1.56	0.37	0.81
Torreyol	0.10	0.08	0.14	0.07	0.36	0.48	0.78	0.42	0.23	1.05	0.21	0.22
γ-Cadinene	0.16	0.22	0.06	0.17	0.12	0.11	0.40	0.33	0.31	-	0.08	-
Caryophyllen oxid	0.27	0.29	0.11	0.24	0.13	0.14	0.16	0.11	0.15	-	0.29	0.19
Carotol	0.13	0.18	0.10	0.10	0.25	0.16	0.34	0.25	0.27	-	0.31	0.31

were recorded in the content of some components of thyme oil as affected with soil types and irrigation intervals. Phenolic compounds are the aroma principles in this chemo type of thyme, the most important compounds are the thymol (39.49-71.32%) and carvacrol (0.09-2.10%). Followed by monoterpene hydrocarbons ρ-cymene 3.72-34.93%), γ-terpinene (1.36-5.70%), myrcene (2.74-3.91%) and α-pinene (1.61-3.46%). Linalool (0.15-5.98%) and boreneol (2.08-5.84%), were dominant among monoterpenic alcohols. Trans-caryophyllene (0-1.94%), germacrene D (0.21-1.56%), γ-cadinene (0-0.40%) were the most abundant sesquiterpenes in the oil. Among oxygenated sesquiterpenes, caryophyllene oxide was the most abundant component (0-0.29%). These results agreed with that reported by Baranauaskiene *et al.* [6], who stated that the characteristic compounds of *T. vulgaris* essential oil have been established, namely: Thymol (44.4-58.1%). ρ-cymeme (9.1-28.5%), γ-terpinene (6.9-18.9%) and carvacrol (2.4-4.2%). Ozcan and Chalchar [22] found that the essential oil of *T vulgaris* was characterized with high content of thymol (46.2%), γ-terpinene (14.1%), ρ-cymeme (9.9%), linalool (4.0%), myrecen (3.5%), α-pinene (3.0%) and α-thujene (2.8%).

Among the treatments, increasing the period between irrigation, every 10 days gave the highest relative constituents of the most important compounds, i.e. the thymol which recorded 71.32, 50.68 and 47.71% in sandy, calcareous and clay loam soil, respectively, this effect was accompanied with a decrease in ρ-cymene, which gave 3.72, 26.78 and 26.29% in sandy, calcareous and clay loam soil, respectively followed by carvacrol which gave the highest percentage (2.10%) in plants grown in sandy soil and irrigated every 10 days. As well as, it gave the highest percents of α-humulene (2.74%), germacrene D (1.56%) and torreyol (1.05%). On the other hand monoterpen hydrocarbon, α-pinene (3.46%), myrcene(3.91%), ρ-cymene(33.91%) and γ-terpinene (5.70%) showed the highest percentage with plant grown in calcareous soil and irrigated every 5 days. Having a look to the relation between the phenolic compound, thymol and its hydrocarbon procures, ρ-cymene, we observed a negative relation between these two compounds under stress conditions (drought). Increasing irrigation intervals to 10 days increased thymol percentage on the compensation of ρ-cymene in sand soil. This means that the rate of transformation of ρ-cymene to phenolic compound thymol is higher under stress condition. These findings support the conclusion that the phenolic compound increase under stress condition. These findings agree with those of Omer [23] on *Origanum syriacum* and Omer *et al.* [24] on *Majorana hortenses*.

These results show that it is possible to increase the content of pharmacologically desirable compounds by manipulating agricultural techniques such as irrigation (water stress). At the different soil type used, increasing the period between irrigation, every 10 days gave the highest relative phenols constituents of thyme as of the most important compounds. Several factors may affect the levels of the active principles of plant material during collection, processing and storage. Indeed, biotic and a biotic stresses exert a considerable influence on the levels of secondary metabolites in plants [7]. Drought stress induces the biosynthesis of isopentenyl pyrophosphate, the primary precursor of terpenes in plants, [25, 26]. isopentenyl diphosphate isomerases is responsible for the isomerization of isopentenyl diphosphate to dimethylallyl diphosphate to form the isoprene unit, the basic compound for the syntheses of all terpenes. As well as Abreu and Mazzafera [27] indicated that a water deficit influences the content of active constituents of *Hypericum brasiliense* and may also be associated with an increase in secondary metabolites through the reallocation of the assimilated carbon as plant growth is progressively reduced. The physiological relevance of this phenomenon in terms of the cost to fitness is unclear, although for phenolics with an antioxidant capacity it may be related to a mechanism to counteract the deleterious effects of ROS[28].

In conclusion, these results show that it is possible to increase the content of pharmacologically desirable compounds of *Thymus vulgaris* plant. Increasing the period between irrigation, every 10 days gave the highest relative constituents of the most important compounds, i.e. thymol which recorded 71.32, 50.68 and 47.71% in sandy, calcareous and clay loam soil, respectively. And the rate of transformation of ρ-cymene to phenolic compound thymol is higher under stress conditions

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