Int. Agrophysics, 2009, 23, 269-275

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Effect of water stress and nitrogen fertilizer on herb and essential oil of oregano

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Received January 23, 2009; accepted May 22, 2009

A b s t r a c t. Two pot trials were carried out during the 2006 and 2007 seasons to investigate the impact of water stress treatments (80, 60, and 40% available soil moisture) and/or nitrogen fertilizer levels (0, 0.6, 0.9 and 1.2 g N pot $^{-1}$ as ammonium sulphate) on the fresh mass of herb and essential oil of oregano plants. Supplying plants with a water level of 80% available soil moisture and with 1.2 g N pot $^{-1}$ were effective in raising the productivity of herb and the content and yield of essential oil. The interaction between these two treatments gave the best results. Concerning essential oil constituents, carvacrol was the major compound, followed by p-cymene, γ-terpinene was the third component.

K e y w o r d s: *Origanum vulgare* L., water stress, nitrogen fertilizer, fresh herb yield, essential oil, GLC analysis

INTRODUCTION

Oregano (*Origanum vulgare* L.) belongs to the *Lamiaceae* family, which is indigenous to the Mediterranean region. It also is distributed and cultivated in many areas of the mild, temperate climates of Europe, Asia, North Africa, and America (Ietswaart, 1980; Goliaris *et al.,* 2002). Oregano plays a primary role among culinary herbs in world trade. Traditionally, leaves and flowers of oregano are used in Lithuania mostly for their beneficial properties to cure cough and sore throats and relieve digestive complaints (Ien *et al.,* 2008). Oregano contains essential oils, rich in the two isomeric phenols carvacrol and thymol (Fleisher and Sneer, 1982; Kokkini and Vokou, 1989; Vokou *et al.,* 1993). The use of oregano as a medicinal plant is attributed to the biological properties of the herb and its essential oil composition. Findings report that oregano is antimicrobial (Chun *et al.,* 2005; Didry *et al.,* 1993; Paster *et al.,* 2005), an antioxidant (Capecka *et al.,* 2005; Jałoszyński *et al.,* 2008), and probably stimulates the appetite (Ien *et al.,* 2008).

The content of essential oils and their composition are affected by different factors, including genetic makeup (Muzik *et al.,* 1989) and cultivation conditions, such climate, habitat, harvesting time, water stress, and the use of fertilizer (Min *et al.,* 2005; Stute, 2006).

Plant reactions are affected by the amount of soil water directly or indirectly. Drought stress limits the production of 25% of the world's land (Delfine *et al.,* 2005). Water stress in plants influences many metabolic processes, and the extent of its effects depends on drought severity. The optimization of irrigation for the production of fresh herbs and essential oils is important, since water is a major component of the fresh produce and affects both mass and quality (Jones and Tardien, 1998). Water deficit in plants may lead to physiological disorders, such as a reduction in photosynthesis and transpiration (Sarker *et al.,* 2005), and in the case of aromatic plants may cause changes in the yield and composition of their essential oils. For example, water deficit decreased the oil yield of rosemary (*Rosmarinus officinalis* L., Singh and Ramesh, 2000) and anise (*Pimpinella anisum* L., Zehtab-Salmasi *et al.,* 2001). By contrast, water stress caused an increase in oil yield of citronella grass (*Cymbopogen winterianus* Jowitt.) expressed on the basis of plant fresh mass. The severity of the water stress response varied with cultvar and plant density (Fatima *et al.,* 2000). The improvement of plant nutrition can contribute to increased resistance and production when the crop is submitted to water stress.

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Plant nutrition is one of the most important factors that increases plant production. Nitrogen is most recognized in plants for its presence in the structure of the protein molecule. In addition, nitrogen is found in such important molecules as purines, pyrimidines, porphyrines, and coenzymes. Purines and pyrimidines are found in the nucleic acids RNA and DNA, which are essential for protein synthesis. The porphyrin structure is found in such metabolically important compounds as the chlorophyll pigments and the cytochromes, which are essential in photosynthesis and respiration. Coenzymes are essential to the function of many enzymes. Accordingly, nitrogen plays an important role in synthesis of the plant constituents through the action of different enzymes. Nitrogen limiting conditions increase volatile oil production in annual herbal plants. Nitrogen fertilization has been reported to reduce volatile oil content in *Juniperus horizontalis* (creeping juniper) (Fretz, 1976), although it has been reported to increase total oil yield in thyme (*Thymus vulgaris* L.) (Baranauskienne *et al.,* 2003). However, studies on agronomic factors such as water stress and nitrogen fertilization on yield and essential oils of oregano have not been investigated thoroughly until now.

This study aimed to evaluate the effect of nitrogen fertilization and irrigation regimes on the fresh herb yield and essential oil content and their main constituents of *Origanum vulgare* L.

MATERIALS AND METHODS

The experiment was carried out under the natural conditions of the greenhouse of the National Research Center, Dokki, Giza, Egypt, during the two seasons of 2006 and 2007. Seeds of oregano were obtained from Jellitto Standensamen Gmbh, Schwarmstedt, Germany and were seeded in the nursery on 15th November 2005 and 2006.

The seedlings were transplanted into pots (30 cm diameter, 50 cm depth) on the 15th February of each season. Each pot contained three seedlings and was placed in full sun light. Each pot was filled with 10 kg of air dried soil.

The soil related to the Typic Torrifluvents. The soil texture was sandy loam, having a physical composition as follows: 44.5% sand, 28.8% silt, 26.7% clay, and 0.85% organic matter. The results of soil chemical analysis were as follows: pH – 8.25; EC (dS m^{-1}) – 0.87; and total nitrogen – 0.11%; available phosphorus – 2.33 mg 100 g^{-1}; potassium – 0.019 mg 100 g^{-1}; field capacity (FC) and wilting point (WP) were determined according to the pressure membrane methods. Field capacity, permanent wilting point, available soil moisture (ASM) and bulk density (BD), as means over the two seasons were: 34.5, 16.0, 18.5%, and 1.36 g cm^{-3}, respectively. The all properties were determined by the standard methods.

The experimental layout was factorial in a complete randomized design (CRD), with three replications. Each replication contained seven pots, while the pot contained three plants. The study contained 12 treatments, which represented all the combinations between 4 nitrogen fertilizer dosages [0 (N0), 0.6 (N1), 0.9 (N2) and 1.2 (N3) g N pot^{-1} as ammonium sulphate (20.5%)]. Ammonium sulphate treatments were applied as a top dressing application and divided into two equal portions. The first portion was added one month after transplanting, and the second N addition, was added five months after transplanting. Then, after the first N addition, irrigation treatments at 80% (I-80), 60% (I-60) and 40% (I-40) available soil moisture were equal to 30.8, 27.1, and 22.6% soil moisure. Pots were weighted daily and when soil moisture percentage reached the aforementioned points, pots were irrigated to reach field capacity (34.5% soil moisture). The differences between the needed soil moisture for the previous treatments and field capacity were calculated and added to the pots in the different treatments. The amounts of the irrigation water during the growing seasons were summed together to estimate plant water requirements for the different treatments.The amounts of water added for each treatment are shown in (Table 1). The meteorological data at Giza, Egypt during the two growing seasons are shown in (Table 2). Plant fresh mass (g $plant^{-1}$) of each replicate was determined in the first and second cuts after 105 and 210 days from transplanting, respectively. The essential oil percentage was determined in the fresh herb of each replicate. To extract and quantify the essential oils, a mass of 100 g of fresh herb, during two cuts in both seasons was separately subjected to hydro-distillation for 3 h using a modified Clevenger apparatus (Gunther, 1961). Essential oil percentage of each replicate was determined and expressed as (%), while essential oil yield per plant was expressed as ml $plant^{-1}$. The essential oils of each treatment were collected and dehydrated over anhydrous sodium sulphate and kept in a refrigerator until gas-liquid chromatography (GLC) analyses. The GLC analysis of the oil samples was carried out in the second season using a Hewlett Packard gas chromatograph apparatus at the Central Laboratory NRC with the following specifications – instruments: Hewlett Packard 6890 series, column; HP (Carbwax 20M, 25 m length x 0.32 mm I.D); film thickness: 0.3 mm; sample size: 1 μl; oven temperature: 60-190°C; program temperature: 60°C/2 min, 8°C/min, 190°C /25 min; injection port temperature: 240°C; carrier gas: nitrogen; detector temperature (FID): 280°C; flow rate: N_2 3 ml min^{-1}, H_2 3 ml min^{-1}, air 300 ml min^{-1}. Main compounds of the essential oil were identified by matching their retention times with those of the authentic samples that were injected under the same conditions. The relative percentage of each compound was calculated from the peak area corresponding to each compound. Except for the constituents of the essential oils, the data of this experiment were statistically analyzed using a LSD at the 5% level (Steel and Torrie, 1980).

T a b l e 1. The amounts of water added for each treatment during the two growing seasons

Season	Available soil moisture (l pot^{-1}) (%)		
	40	60	80
2006	39.75	87.70	167.50
2007	43.00	89.00	171.80

RESULTS AND DISCUSSIONS

Data presented in Table 3 indicated that irrigation regimes and/or nitrogen fertilization affected plant fresh mass in both cuts of both seasons. Increasing water amounts increased plant fresh mass. The highest mean values due to irrigation treatments were recorded with plants that received the highest amounts of water. The pronounced effect of increased irrigation on fresh herb yield may be attributed to the availability of sufficient moisture around the root concentrated and thus a greater proliferation of root biomass resulting in the higher absorption of nutrients and water leading to production of higher vegetative biomass (Singh *et al.,* 1997). It was found that increasing levels of water stress reduce growth and yield due to reduction in photosynthesis and plant biomass. Under increasing water stress levels photosynthesis was limited by low CO_2 availability due to reduced stomatal and mesophyll conductance. Drought stress is associated with stomatal closure and thereby with decreased CO_2 fixation. The superiority of the plants that received the highest rate of irrigation treatments in producing the heaviest total plant fresh mass was in agreement with that of Thabet *et al.* (1994), El-Naggar *et al.* (2004) and Moeini Alishah *et al.* (2006). Increasing nitrogen doses increased plant fresh mass at all doses except for the 0.9 g N pot $^{-1}$ in the first cut in both seasons. These pots had reduced plant fresh mass compared to the 0.6 g N pot $^{-1}$ treatment. The interaction effect was significant in both cuts of both seasons. The highest values of plant fresh mass were produced from the treatment irrigated at 80% available soil moisture and fertilized with 1.2 g N pot $^{-1}$ at the two cuts in both seasons. The stimulation effects of applying nitrogen on vegetative growth may be attributed to the well known functions of nitrogen in plant life, as described in the introduction. Moreover, nitrogen is involved in many organic compounds of the plant system. A sufficient supply of various nitrogenous compounds is, therefore, required in each plant cell for its proper functioning. Generally, the enhancing effect of N-fertilization on plant growth may be due to the positive effects of nitrogen on activation of photosynthesis and metabolic processes of organic compounds in plants which, in turn, encourage plant vegetative growth. The increase in the fresh herbage yield with nitrogen fertilization is in agreement with results reported were recorded by Agamy (2004); Said-Al Ahl (2005) and Mauyo *et al*. (2008).

In both cuts in both seasons, both water quantities and nitrogen application and their interaction affected the percentage of essential oils in oregano (Table 3). The mean values of essential oils due to water irrigation treatments showed that increasing water supply from 40 to 60% available soil moisture increased the percentage of essential oils. This increment reached *ca* 27% in the first cut in both seasons, while this increment was *ca* 12 % in the second cut. Increasing water supply from 60 to 80% available soil moisture decreased percentage of essential oils. The decrement reached *ca* 13% in the first cut in both seasons and 15% in the second cut. In other words, the medium stress condition (60% available soil moisture treatment) accelerated the production of essential oils, while the severe stress conditions due to water (40% available soil moisture treatment) decreased the biosynthesis of the essential oils. Similar results were recorded by Singh *et al.* (1997) and Fatima *et al.* (2000). The mean values of essential oils due to nitrogen

T a b l e 2. Meteorological data at Giza (CLAC, Egypt) during the two growing seasons

Months	2006					2007				
	T(°C)		Rs (MJ m^{-2} d^{-1})	RH (%)	ETp (mm d^{-1})	T(°C)		Rs (MJ m^{-2} d^{-1})	RH (%)	ETp (mm d^{-1})
	Max	Min				Max	Min			
February	22.7	9.9	17.0	52.4	2.4	19.7	10.8	16.4	59.2	2.4
March	24.6	10.5	19.2	50.4	3.1	22.8	12.0	18.1	54.1	3.4
April	27.4	15.6	23.0	48.5	4.6	26.4	14.5	19.4	53.7	5.1
May	31.0	16.9	24.7	48.3	6.8	32.0	19.0	21.1	49.2	6.9
June	34.5	21.1	25.9	47.2	7.3	34.5	21.6	24.1	51.5	7.4
July	33.8	21.8	23.2	48.5	7.1	34.8	23.7	22.7	57.5	7.1
August	34.6	23.0	21.3	50.8	6.8	33.7	29.7	20.6	59.9	7.0
September	32.5	21.3	20.2	50.8	5.9	31.4	21.4	19.9	61.1	6.1

Monthly average: T – temperature, Rs – solar radiation, RH – relative humidity; ETp – potential evapotranspiration.

Table 3. Effect of water stress and / or nitrogen fertilizer on the herb fresh mass, essential oil percentage and essential oil yield of *Origanum vulgare* L. plants at the two cuts during the two seasons

Treatments		Fresh mass of herb (g plant $^{-1}$)				Essential oil (%)				Essential oil yield (ml plant^{-1})			
		2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
		Number of cuts											
		1	2	1	2	1	2	1	2	1	2	1	2
Independent factors													
Irrigation	I-40	5.78	5.80	8.97	8.99	0.466	0.466	0.322	0.323	0.026	0.026	0.028	0.028
	I-60	7.25	7.29	13.34	13.23	0.592	0.592	0.363	0.364	0.042	0.042	0.047	0.047
	I-80	8.76	8.84	15.55	15.60	0.513	0.513	0.305	0.307	0.045	0.046	0.048	0.048
Nitrogen	N0	5.91	6.04	10.61	1054	0.518	0.517	0.313	0.313	0.030	0.030	0.032	0.032
	N1	7.65	7.64	12.48	12.44	0.482	0.482	0.297	0.298	0.036	0.036	0.036	0.036
	N2	7.15	7.13	13.42	13.43	0.533	0.533	0.348	0.348	0.037	0.037	0.045	0.045
	N3	8.34	8.44	13.97	14.03	0.563	0.564	0.363	0.365	0.048	0.049	0.051	0.051
Interaction combinations													
I-40	N0	5.17	5.36	8.12	8.15	0.496	0.496	0.283	0.281	0.025	0.026	0.022	0.022
	N1	7.17	7.11	10.37	10.40	0.421	0.420	0.316	0.316	0.030	0.029	0.032	0.032
	N2	5.66	5.59	8.73	8.73	0.540	0.540	0.348	0.350	0.030	0.029	0.030	0.030
	N3	5.13	5.17	8.68	8.71	0.408	0.410	0.343	0.345	0.020	0.021	0.029	0.030
I-60	N0	5.86	6.02	11.10	10.77	0.580	0.580	0.381	0.380	0.033	0.034	0.042	0.040
	N1	7.61	7.58	13.18	13.00	0.620	0.620	0.303	0.306	0.047	0.046	0.039	0.039
	N2	7.45	7.43	13.80	13.80	0.486	0.486	0.420	0.420	0.036	0.036	0.057	0.057
	N3	8.10	8.14	15.31	15.36	0.683	0.683	0.350	0.350	0.055	0.055	0.053	0.053
I-80	N0	6.72	6.75	12.63	12.70	0.478	0.476	0.275	0.280	0.032	0.032	0.034	0.035
	N1	8.17	8.23	13.91	13.93	0.406	0.406	0.273	0.273	0.033	0.033	0.038	0.037
	N2	8.34	8.37	17.75	17.76	0.573	0.573	0.276	0.275	0.047	0.047	0.049	0.048
	N3	11.81	12.03	17.92	18.03	0.598	0.600	0.398	0.400	0.070	0.072	0.071	0.072
Nitrogen (N)*		0.177	0.110	0.392	0.213	0.025	0.005	0.013	0.010	0.0012	0.0008	0.013	0.010
Irrigation (I)*		0.153	0.096	0.339	0.184	0.022	0.004	0.011	0.009	0.0010	0.0007	0.011	0.009
(N) x (I)*		0.306	0.192	0.779	0.369	0.044	0.009	0.022	0.018	0.044	0.0010	0.022	0.018

*LSD at 5% level. N – nitrogen fertilizer, N0 – control, N1 – 0.6 g N pot^{-1}, N2 – 0.9 g N pot^{-1}, N3 – 1.2 g N pot^{-1}; I – irrigation of: 40, 60, 80% – available soil moisture, respectively.

application at 0.6 g N pot $^{-1}$ decreased in both cuts of both seasons. These reductions reached *ca* 6% in the first cut and *ca* 5% in the second cut in both seasons. The interaction between water supply and nitrogen fertilization on the essential production in oregano showed different trends. Generally, the maximum essential oil content was observed in the fresh herb of plants that received 60% available soil moisture and fertilized with 1.2 g N pot $^{-1}$ in the first cut, whilst, in the second cut, the maximum essential oil content was recorded in plants that received 60% available soil moisture and fertilized with 0.9 g N pot $^{-1}$. Nitrogen fertilization might enhance the essential oil biosynthesis processes through its direct or indirect role in plant metabolism resulting in more plant metabolites. These finding are in agreement with those of Omer (1998) and Omer *et al.* (2008), who said that nitrogen fertilizer was effective in increasing essential oil of *Origanum syriacum* and *Ocimum americanum*, respectively.

The essential oil yield of oregano (ml plant $^{-1}$) was affected by water quantities and/or nitrogen fertilization in both cuts of both seasons. Increasing water quantities from 40 to 60% available soil moisture increased oil yield in both cuts of both seasons. These increments were 61 and 68%in the first and second cut of both seasons, respectively. Increasing irrigation water quantities from 60 to 80% available soil moisture increased oil yield in both cuts of both seasons but the increments were less than those that resulted from 60% available soil moisture. These increments were *ca.* 8 and 2% in the first and second cut of both seasons, respectively. Moisture stress also decreased fresh herb yield, so there was a decrease in oil yield with an increase in moisture stress. These findings agree with those of Singh and Ramesh (2000) and Zehtab-Salmasi *et al.* (2001). They found that water deficit decreased the oil yield of rosemary (*Rosmarinus officinalis* L.) and anise (*Pimpinella anisum* L.), respectively. Increasing nitrogen doses resulted in gradual and significant increase in essential oil yield in both cuts of both seasons. The higher the amount of the nitrogen, the higher was the oil yield. The trend of the response of essential oil yield to nitrogen application differs due to the added quantities of water, which explains the interaction effect of both factors. Generally, the highest essential oil yield (ml plant $^{-1}$) was obtained from plants received 80% available soil moisture and fertilized with 1.2 g N pot $^{-1}$ in both cuts of both seasons. The response of volatile oil content to nitrogen fertilization might be attributed to *de novo* meristemic cell metabolism in building dry matter with essential oil production. These results agree with those of Omer (1998) and Omer *et al.* (2008), who found a positive correlation between nitrogen fertilizer and essential oil content in herbage of *Origanum syriacum* and *Ocimum americanum*, respectively in all cuttings.

To study the effect of irrigation levels and/or nitrogen fertilization on the main constituents of the essential oil, the oil of each treatment was separately subjected to gas liquid chromatography and the main compounds and their relative percentages are shown in (Table 4). Carvacrol, a phenolic compound, was found to be the first major compound and ranged from 42.96 to 82.44%. Its maximum content was observed in the essential oil of the herb that received 80% available soil moisture alone in the second cut, while the minimum content was recorded with plants that received 60% available soil moisture and fertilized with 1.2 g N pot $^{-1}$ in the first cut. The second main compound was identified as the monoterpine, p-cymene, which ranged from its maximum content (24.52%) with 40% available soil moisture treatment alone to its minimum relative percent (2.07%) with 80% available soil moisture treatment alone in the second cut. Generally, the main differences were observed with the two phenolic compounds carvacrole and thymol, and their hydrocarponic precursors terpinene and p-cymene. The phenolic compounds increase in hot seasons at the expense of their preceding precursors. In other words, the relative percentage of carvacrol was higher in the second cut than in the first cut. This may be attributed to the effect of the environmental factors especially non-edaphic factors, since these plants grew in summer months under high temperatures and received more solar energy than those grown in the spring summers (Table 2). These conditions accelerate the transformation of terpinene and p-cymene to phenolic compounds. These findings agree with those of Omer (1998) on *Origanum syriacum* and Omer *et al.* (1994) on marjoram. In this respect, Piccaglia and Marotti (1993) reported that during their two-year study differences in relative amounts of thymol, carvacrol, γ–terpinene, and p-cymene, essential oils of *Satureja montana* which is grown in Italy, could be attributed to the effects of environmental conditions. The most interesting observation that the treatments showed was that the maximum carvacrol content resulted from the minimum content of γ-terpinine (0.65%). However, the maximum content of γ-terpinine (12.7%) was observed with the treatment that resulted in the minimum content of carvacrol. This observation supports the idea that terpinene and p-cymene are the biogenetic precursors of thymol and carvacrol and that there is a negative relationship between γ-terpinine and carvacrol. Total oxygenated compounds were higher than nonoxygenated compounds and varied according to the applied treatments. The maximum value of oxygenated compounds (85.5%) was recorded in the essential oils of plants that were irrigated with 80% available soil moisture, while the minimum value (45.77%) was recorded in the essential oils of plants that were irrigated with 60% available soil moisture and fertilized with 1.2 g N pot $^{-1}$. The same trend was observed with carvacrol. More than 85% of the identified compounds were found to be monoterpenes, while the rest of the identified compounds were found to be sesqueter-penes. We conclude that irrigation of *Origanum vulgaris* at 80% available soil moisture and fertilizing it with 1.2 g N pot $^{-1}$ result in the highest herbage yield and oil content.

T a b l e 4. Effect of water stress and / or nitrogen fertilizer on the constituents of *Origanum vulgare* L. plants during two cuts in the second season (2007)

Components	1st cut						2nd cut					
	Treatments											
	40	60	80	40+N2	60+N3	80+N3	40	60	80	40+N2	60+N3	80+N3
α-thujene	0.22	0.19	–	0.15	0.33	0.14	–	–	0.96	2.90	–	0.50
α-pinene	0.13	0.22	0.16	0.21	0.19	0.09	–	–	–	0.17	0.19	–
β-pinene	2.40	2.57	1.76	2.22	2.31	1.45	1.89	1.32	0.33	0.35	0.72	0.57
α-terpinene	1.72	2.04	1.18	1.51	1.79	1.22	1.63	1.19	1.07	1.13	0.75	1.24
P-cymene	23.88	16.59	14.91	24.24	21.88	19.21	24.52	16.70	2.07	9.68	9.22	12.19
Limonene	0.40	1.23	0.15	0.90	0.73	–	1.12	–	–	–	0.35	–
γ- terpinene	10.68	13.09	5.03	9.40	12.70	7.52	10.06	6.22	0.65	2.61	4.58	4.49
Linalool	0.28	0.24	0.54	0.45	0.34	0.48	0.38	0.36	0.72	0.76	0.56	0.54
Borneol	0.18	0.21	0.13	0.19	0.25	0.21	0.20	–	–	–	0.09	0.13
Terpinene-4-ol	0.50	0.43	0.63	0.52	0.50	0.66	0.50	0.65	0.95	0.73	0.67	0.72
α-terpineol	–	0.04	–	0.05	–	0.07	–	–	–	–	–	–
Thymol	1.84	1.41	1.60	1.57	1.13	2.25	1.45	1.05	1.02	1.88	1.18	1.79
Bornyl acetate	0.16	0.08	–	0.18	–	0.32	–	–	–	–	0.16	0.26
Carvacrol	47.70	45.88	63.36	48.06	42.96	54.42	48.79	56.81	82.44	70.24	71.11	66.03
Carvacrol acetate	0.66	0.64	0.85	0.83	0.59	0.89	0.87	1.00	0.37	0.95	0.98	0.08
Elemene	0.38	0.31	0.14	0.30	0.26	0.39	0.42	0.18	–	0.17	0.17	0.17
Caryophyllene	0.32	0.40	0.40	0.40	0.40	0.56	0.12	0.28	0.36	0.85	0.52	0.41
Germacrene D	0.70	0.64	0.65	0.94	0.47	1.04	1.17	1.42	1.16	0.17	1.33	0.96
Cadinene	0.11	0.08	0.14	0.10	–	0.14	0.17	0.22	–	0.18	0.19	0.33
Caryephyllene oxide	0.17	0.13	0.08	0.19	–	0.26	–	–	–	–	0.09	0.13
Identified compounds	92.43	86.42	91.71	92.41	86.83	94.32	93.27	87.40	92.33	92.94	92.86	90.54
Oxygenated compounds	51.49	49.08	67.19	52.04	45.77	59.56	52.19	59.87	85.50	74.56	74.84	69.68
Hydrocarbon compounds	40.94	37.34	24.52	40.37	41.06	34.76	41.08	27.53	6.83	18.38	18.02	20.86
Unidentified compounds	7.57	13.58	8.29	7.59	13.17	5.68	6.73	12.60	7.67	7.06	7.14	9.46

CONCLUSIONS

1. Nitrogen fertilizer increased herb fresh yield and essential oil production under well-watered conditions at 80% available soil moisture, also under moderate-watered conditions at 60% available soil moisture and under water deficit conditions at 40% available soil moisture.

2. Increasing irrigation levels increased the production of oregano and the optimum irrigation levels for the highest yields of fresh herb and essential oils was 80% available soil moisture.

3. Supplying plants with a water level of 80% available soil moisture and with 1.2 g N pot^{-1} (I-80%+ N3) gave the best result in case of herb fresh yield and essential oil production.

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