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ORIGINAL PAPER

Plants of the same place do not have the same metabolic pace: soil properties affect differently essential oil yields of plants growing wild in semiarid Mediterranean lands

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Abstract

The chemical composition and structure of the soil strongly affect the growth and development of plants. Ecophysiologically, the effects of soil are translated in changes in plant primary and secondary metabolism. Among the secondary metabolites of plants affected by soil properties are essential oils. In this work, we resume our study on the effect of soil properties on the accumulation of essential oils in two spontaneous plants growing in Algerian semiarid region: *Rosmarinus officinalis* L. and *Thymus algeriensis* Boiss & Reut. after studying the effect of climate on these plants in the same period (2010–2014) and at the same collection site in our previous study. The results showed significant differences ($P < 0.001$) between the oil contents during the period of the study in both plants. The yield of oils was significantly affected by the soil parameters. The pH, total calcium carbonate (CCE), active calcium carbonate (ACCE), and N:P ratio exhibited significant positive correlation ($P < 0.001$ and $P < 0.05$) with *Rosmarinus officinalis* essential oil amount contrary to total nitrogen and salinity that had negative effects. Regarding *Thymus algeriensis*, the pH, salinity, and N:P ratio had a significant positive effect ($P < 0.001$) on the content of essential oil. However, CCE, ACCE, and carbon exerted negative effects on oil amount.

Keywords *Rosmarinus officinalis* · *Thymus algeriensis* · Essential oils · Edaphic effects · Dry lands · Plant-soil interaction · Secondary metabolism · C:N:P ratios

Introduction

Plants' growth, breeding, dispersal, and distribution are closely linked to environmental conditions of their habitat, where many factors external to the plants influence their development (Aboukhalid et al. 2017; Chenchouni 2017). The environmental conditions to which the plant is exposed control the expression of plant genes and thus modify the development of phytomass and determine the switching between primary and secondary metabolic pathways and also secondary transformations (Ncube et al. 2012; Bhatla 2018; Németh-Zámboriné et al. 2019). Among these factors, the climatic and edaphic variables (such as temperature, humidity, photoperiod duration, wind speed, and various physicochemical properties of the soil) prevail on biotic interactions and thus represent the key determinants of the physiology and metabolism of the plant and consequently of its growth. Accordingly, changes in environmental factors can greatly induce significant variation in the quantity and quality of the essential oils (EOs) produced (Niinemets et al. 2013; Vaičiulytė et al. 2017; Mehalaine and Chenchouni 2019, 2020). For slight regional or large-scale changes in these factors, the impact on the global EOs market may be drastic (Carrubba and Catalano 2009; Aboukhalid et al. 2017).

Several studies have clarified the impact of soil and climate on different plant oils (Perry et al. 1999; Razmjoo et al. 2008;

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Msaada et al. 2009; Hasani et al. 2017; Vaičiulytė et al. 2017; Mehalaine and Chenchouni 2019). The impact of pedological and climatological factors on medicinal plants could be reflected in their chemical composition (Herlina et al. 2017). The type and chemical composition of the soil determine the volatile chemical constituents of EOs (Figueiredo et al. 2008; Aboukhalid et al. 2017). The role and effect of mineral nutrients have been deeply studied on the morphology, physiology, and biochemistry of different cultivated plants, which has made it possible to highlight immense agronomic information (Singh et al. 2016; Herlina et al. 2017; Jeshni et al. 2017). In contrast, the agronomic catalogs of wild plants like most medicinal species are still very few.

Among the aromatic plants which are subject to environmental constraints are *Rosmarinus officinalis* L. and *Thymus algeriensis* Boiss & Reut. *Rosmarinus officinalis* L. (rosemary) is native to the Mediterranean region (Quezel and Santa 1963). Rosemary is a highly branched shrub up to 2 m high, with evergreen and fragrant leaves. Rosemary is a wild common species in Algeria and it is among the most popular plants, since it is found in all gardens and parks (Beniston 1984). Thanks to its therapeutic properties, rosemary is very appreciated in folk medicine and culinary in Algeria (Beniston 1984; Beloued 2005). *Thymus algeriensis* Boiss & Reut. (thyme of Algeria, thyme) is an endemic species to North Africa: Algeria, Morocco, Tunisia, and Libya (Quezel and Santa 1963). *Thymus algeriensis* is a woody plant with very aromatic glandular leaves. This herb is widely used in cooking and to treat various illnesses in Algeria (Beloued 2005; Dob et al. 2006; Hazzit et al. 2009). Like all the African medicinal plants, these two plants are threatened by decline because of the great demand for various purposes (Moyo et al. 2015). In fact, their economic importance and their appreciation in herb medicine guides are related to their aromatic character. Their ability to synthesize fragrant EOs gives them a valuable place in the list of medicinal and aromatic plants.

The quantity and quality of EOs are influenced by the environmental factors under which the plant grows (climatic and edaphic properties, intra- and inter-competitions, herbivory, cultivation practices, irrigation regime, etc.) on the one hand, and by variables related to the manipulation of plant material and EO extraction (harvest period, conservation method of raw material, part of the plant used, drying method and duration, fragmentation method, and extraction technique) on the other hand (Razmjoo et al. 2008; Ghasemi Pirbalouti et al. 2013; Jeshni et al. 2017; Said-Al Ahl et al. 2019; Zouaoui et al. 2020). Given the multitude, complexity, and synergy of interactions between these factors involved in the metabolism, accumulation, and yield efficiency of plant EOs, it is very difficult if not impossible to predict or standardize the yield of EOs especially in harsh and unpredictable environments like those of arid and semiarid hot regions (Dob et al. 2006; Hazzit et al. 2009; Mehalaine et al. 2017; Mehalaine and Chenchouni 2019; Zouaoui et al. 2020).

In order to examine the effect of mineral salts on phytochemical properties, particularly on EO content of *T. algeriensis* and *R. officinalis*, it is first necessary to assess the impact of soil chemical properties in their natural habitat on their ability to produce and to accumulate EOs.

In our previous work, we investigated essential oil chemical composition of *T. algeriensis* and *R. officinalis* growing under semiarid climate (Mehalaine et al. 2017). In Algeria, there are no works which have attempted to study the effect of climatic and edaphic conditions on the production of essential oils in these species. That is why, in our previous study, we highlighted the effect of climatic factors on the production of EOs in both plants during a long period (Mehalaine and Chenchouni 2019), and in the present research, we provide soil chemical diagnosis in their natural habitat and illustrate the impact of soil parameters on their EO yield in order to understand how these species respond and adapt to semiarid environment by regulating their secondary metabolism.

Materials and methods

Plant material and isolation of essential oils

The flowering tops of *Rosmarinus officinalis* and *Thymus algeriensis* were used for the extraction of EOs. The vegetable matter was harvested at the full flowering phase of both plants. The site of collection was the region of Ain Beida (latitude: 35°47′47″ N, longitude: 7°23′34″ E, elevation: 891 m a.s.l.) in northeastern Algeria. The woody parts were eliminated and the fresh samples were cut into small fragments (0.5–1 cm). Then, the plant fresh matter was dried at room temperature. Eighty grams of plant dry matter were hydrodistillated by using the Clevenger system method for 2 h. The obtained oils were completely separated from the water and kept in glass vials. Then, essential oil yield was evaluated in relation to the weight of plant dry matter (*w*/w) and calculated as follows:

$$\text{EO yield } (\%) = \text{Mass(EOs)}/\text{Mass(plant dry matter)} \times 100$$

Chemical analysis of the soil

Sampling and soil preparation

The collection of the soil samples was carried out randomly at a depth of 30 cm from the same site of the plant collection and in the same period of the plant sample harvest (flowering stage). The soil samples were dried, ground, and then sieved by a 2-mm sieve. The chemical analysis of the soil was carried out according to the standard methods of soil analysis with slight modifications.

pH, salinity, and electrical conductivity (EC)

Twenty grams of the sieved soil was stirred in 50 ml of distilled water for 2 h and then filtered. The pH of the soil was determined using a pH meter on the filtrate obtained (a soil suspension in distilled water). Electrical conductivity and salinity were determined using a conductivity meter on the same soil suspension (Gégout and Jabiol 2001; Mathieu and Pieltain 2003).

Total calcium carbonate equivalent (CCE)

The determination of total $CaCO_3$ percentage (%) was carried out by the volumetric method using the Bernard Calcimeter, by decomposing calcium carbonates with hydrochloric acid and then measuring the volume of released CO_2 (Gégout and Jabiol 2001; Mathieu and Pieltain 2003).

Active calcium carbonate equivalent (ACCE)

The percentage (%) of active $CaCO_3$ was determined by using the Drouineau-Gallet method, using ammonium oxalate which combines with dissolved limestone calcium (active limestone) to form insoluble calcium oxalates. Excess of ammonium oxalate was then assayed by a solution of potassium permanganate in sulfuric medium (Gégout and Jabiol 2001; Mathieu and Pieltain 2003).

Organic carbon (C)

The percentage of organic carbon (C%) was determined by using Anne's method, in which it was oxidized by an excess of potassium dichromate in a sulfuric medium. The excess of dichromate which was not reduced by organic carbon was then titrated by a solution of Mohr's salt which reduced the dichromate in the presence of diphenylamine. The level of organic matter (OM) was then determined as follows: OM (%) = C% × 1.72 (Graffin et al. 1970; Gégout and Jabiol 2001; Mathieu and Pieltain 2003).

Assimilable phosphorus (P)

The extraction and determination of assimilable phosphorus (P_2O_5 ppm) were carried out by using the Joret-Hebert method using a solution of the sieved soil and ammonium oxalate which was stirred for 2 h. After filtration, the concentration of phosphorus in the filtrate obtained was determined by colorimetry based on the formation and reduction of a complex of phosphoric acid and molybdic acid by ascorbic acid. The readings were performed at a wavelength of 650 nm by a spectrophotometer (Morel et al. 1992; Mathieu and Pieltain 2003).

Total nitrogen (N)

Total nitrogen was determined by using the Kjeldahl method. Five grams of the sieved soil was boiled in an amount of concentrated sulfuric acid, the carbon dioxide formed volatilized, and the nitrogen was passed through a solution of ammonium sulfate. The ammoniacal salt was then decomposed by a strong base (soda). The ammonia was distilled and captured by a determined volume of sulfuric acid. After that, the rest of the sulfuric acid which did not react with ammonia was titrated with a soda solution (Mathieu and Pieltain 2003).

Soil C:N, C:P, and N:P ratios

Soil stoichiometric relationships were computed based on the levels of C, N, and P measured above; accordingly C:N, C:P, and N:P ratios were determined (Tian et al. 2010; Ouyang et al. 2017).

Statistical analysis

The generalized linear model (GLM) with Gaussian distribution error and identity link was used to analyze the changes in EO contents in *R. officinalis* and *T. algeriensis* during the period of the study and the interaction "year × species." In addition, multiple comparisons of means were carried out via Tukey's post hoc test to distinguish homogeneous and heterogeneous groups among the 5 years for each plant. The correlation between the chemical parameters of the soil was tested (Pearson correlation matrix) (Fig. 1). The multicollinearity was checked and only eight out of twelve soil parameters were employed as predictable parameters for modeling the variability of EO amounts. These soil variables implemented in statistical modeling included pH, salinity, CCE, ACCE, organic carbon, total nitrogen, and N:P and C:N ratios. Using GLM with Gaussian distribution error and "Identity" link, the impacts of these variables on the variability of annual EO yields were tested for each plant separately. Each GLM was then simplified to obtain the best fitted model with minimum soil variables following the "backward/forward" stepwise selection procedure. The value of Akaike information criterion (AIC) was used as a measure of model fit in ranking the derived GLMs, with the model with the lowest AIC value being considered the "best" (Appendix Table 3). Models in which the difference in AIC relative to the lowest AIC was greater than 2 were not considered. The variation of EOs of each species against every soil parameter with significant effect ($P < 0.05$) in the selected model with best fit was plotted using the package {effects} of the R software (R Core

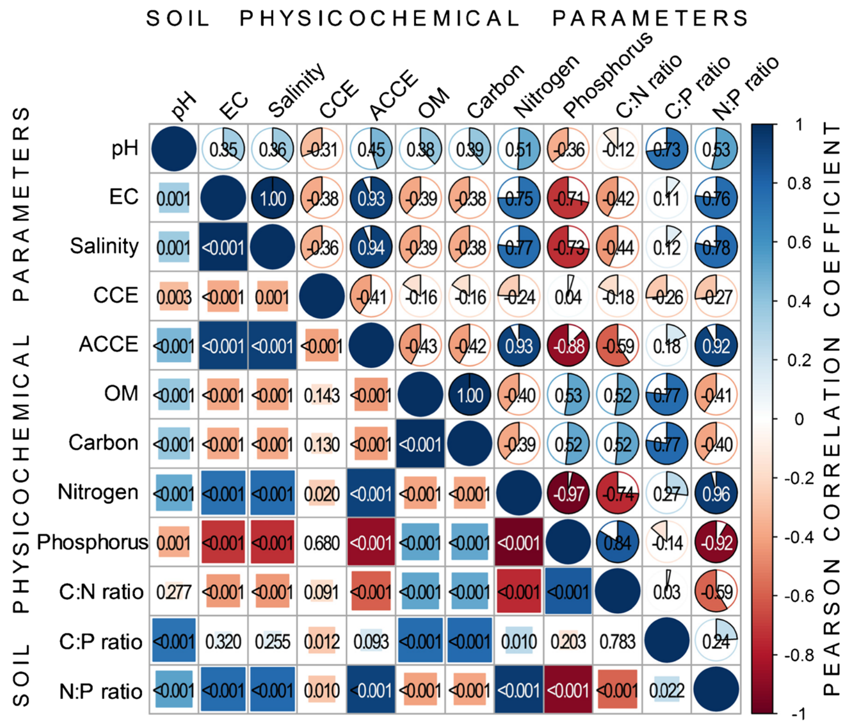

Fig. 1 Correlation matrix applied for soil parameters of the collection site. Values of Pearson correlation tests are given within pie charts as the correlation coefficient, coloration, and pie-chart size (above diagonal) and *P* value (under diagonal)

Team 2019) that was used to carry out all statistical analyses.

Results and discussion

Soil parameter characterization

The values of soil parameters significantly varied ($P < 0.001$ and $P < 0.05$) during the period of the study (2010–2014) except for C:P ratio. According to the obtained data, the soil appeared alkaline with an average pH 7.96 ± 0.08. The salinity was low (186.38 ± 32.70 mg/l). The soil was moderately calcareous with a total calcium carbonate (CCE) percentage of 8.52 ± 3.82% and active calcium carbonate (ACCE) percentage of 7.86 ± 2.50%. The percentage of organic carbon was 3.51 ± 1.59% that is corresponding to the organic matter percentage of 5.99 ± 2.75%. The total nitrogen content was low with an average of 39.66 ± 18.45 mg/100 g soil and the available phosphorus content was also slight (126.85 ± 34.06 ppm) (Table 1).

The variability in the values of soil chemical parameters can be attributed to different factors: climate, microorganism activity, and vegetation (Tian et al. 2010). Ouyang et al. (2017) reported that the variations of vegetation composition affected the amount and the storage of chemical nutrients in the soil such as carbon, nitrogen, phosphorus, and C:N, C:P, and N:P ratios. In addition, the concentrations of organic carbon, total nitrogen, and total phosphorus were significantly influenced by soil pH. According to Castells et al. (2004), the phenolic compounds leached from the green foliage modified the crude mineralization of nitrogen and consequently its content in the soil. Total nitrogen consists of 98 to 99% organic nitrogen. Mineral nitrogen, the percentage of which is very low in soils, comes from the mineralization of organic nitrogen and nitrogen gas fixed by microorganisms (Mengel et al. 2001). Soil pH plays a major role in the availability of phosphorus. In alkaline soils, calcium precipitates phosphorus. After precipitation, phosphorus becomes insoluble and is released very slowly into the soil solution. Therefore, this mineral nutrient is always limited in strongly calcareous soils (Hopkins 2003). Organic carbon constitutes almost half of the organic matter. In semiarid regions, soils generally contain constant content of lime and low quantity of organic matter (Aubert 1965; Aliat et al. 2016).

Correlation between soil parameters

The collinearity test allowed to distinguish 122 significant correlations ($P < 0.05$) out of 132 correlations applied between the soil variables. The correlations between the 12 soil parameters studied were tested in order to eliminate the parameters that are correlated statistically and/or ecologically. According to the correlation matrix (Fig. 1), the most important correlations ($P \leq 0.001$) were observed between electrical conductivity (EC) with salinity ($r = 1$), organic matter (OM) with carbon ($r = 1$), phosphorus with all variables ($P \leq 0.001$) except for CCE ($P = 0.680$), C:N ratio with all parameters ($P < 0.001$) with the exception of pH ($P = 0.277$) and CCE ($P = 0.091$). Collinearity test distinguished 8 parameters out

Table 1 Descriptive statistics of soil variables collected from the habitat of *R. officinalis* and *T. algeriensis* growing wild in Algerian semiarid zone

Soil variables	Descriptive statistics										Type II *F*-tests		
	Mean	SD	SE (m)	IQR	CV	0%	25%	50%	75%	100%	*F*	*P value*	Sig.
pH	7.96	0.08	0.01	0.15	0.01	7.85	7.88	7.93	8.03	8.12	117.80	< 0.001	***
EC (μs/cm)	345.06	58.33	6.15	67.37	0.17	193.00	310.00	349.83	377.37	429.33	38.44	< 0.001	***
Salinity (mg/l)	186.38	32.70	3.45	40.70	0.18	103.00	165.00	192.04	205.70	233.03	39.94	< 0.001	***
CCE (%)	8.52	3.82	0.40	4.29	0.45	3.18	6.36	7.49	10.65	17.50	10.11	0.002	**
ACCE (%)	7.86	2.50	0.26	2.93	0.32	3.00	6.50	8.10	9.43	12.10	67.37	< 0.001	***
OM (%)	5.99	2.75	0.29	2.54	0.46	2.64	4.32	5.58	6.86	14.28	6.06	0.016	*
Carbon (%)	3.51	1.59	0.17	1.43	0.45	1.53	2.56	3.28	3.99	8.30	5.71	0.019	*
Nitrogen (%)	39.66	18.45	1.94	20.53	0.47	5.60	30.80	41.53	51.33	70.93	65.36	< 0.001	***
Phosphorus (ppm)	126.85	34.06	3.59	41.96	0.27	74.43	105.86	121.58	147.82	208.99	44.13	< 0.001	***
C:N ratio	0.17	0.24	0.03	0.13	1.40	0.03	0.05	0.07	0.18	0.93	10.90	0.001	**
C:P ratio	0.03	0.01	0.00	0.01	0.33	0.01	0.03	0.03	0.03	0.05	2.37	0.128	NS
N:P ratio	0.38	0.26	0.03	0.27	0.69	0.03	0.22	0.34	0.48	0.95	86.97	< 0.001	***

See the "Chemical analysis of the soil" subsection for soil variable abbreviations. Statistical symbols and abbreviations: *CV*, coefficient of variation; *IQR*, interquartile range; *SD*, standard deviation; *SE (m)*, standard error of mean; *F*, *F*-statistics; *Sig*., statistical significance of *P* value. ***$P < 0.001$, **$P < 0.01$, *$P \leq 0.05$, ^{NS} $P > 0.05$

of 12 which had a significant effect on the production of EOs in the two plants. In addition, the correlation tests indicated the relationships between soil parameters, which also served to eliminate one of the highly correlated variables like carbon with organic matter (OM) and electrical conductivity (EC) with salinity because these variables ecologically have the same effects on the assimilation of EOs. This approach aimed to analyze the minimum number of soil variables which had the significant effects. Then, the stepwise selection model test was applied to statistically calculate the lowest AIC value that indicated the best fitted multivariate regression model to use. Accordingly, the effects of eight soil parameters (pH, salinity, CCE, ACCE, carbon, total nitrogen, and C:N and N:P ratios) on the variation of yield of EOs for each plant species were independently tested using the generalized linear model (GLM) with Gaussian distribution error and "Identity" link (see the "Statistical analysis" section).

Variations in essential oil content

From the generalized linear model (GLM), very highly significant differences ($P < 0.001$) were observed between the yearly contents of EOs in both plants. *R. officinalis* presented the best yields during 2010, 2012, and 2013 (1.00 ± 0.18%, 0.93 ± 0.05%, and 0.88 ± 0.00%); in 2011 and 2014, rosemary presented lower EO quantities. *T. algeriensis* produced the highest EO quantity in 2013 (1.08 ± 0.02%) followed by 2011 and 2012; the lowest amounts were observed in 2010 and 2014 (Fig. 2).

The variations of EO amounts in both plants are due to the changes of climatic factor performances during the 5 years (2010–2014) and also to the effect of soil parameters. In our previous work, we showed that climatic factors significantly influenced the quantity of EOs in *R. officinalis* and *T. algeriensis* during the years of the study (Mehalaine and Chenchouni 2019). Perry et al. (1999) showed significant changes in the yield and quality of *Salvia officinalis* EOs according to the site and season of harvest.

Herlina et al. (2017) reported that the pedological and climate factors exerted important variations in chemical composition of *Nigella sativa* EOs.

Impact of soil parameters on essential oil content

The results provided by the GLM test indicated significant effects of soil parameters on EO yields in both plants. EO quantity of *R. officinalis* was found positively correlated with pH, total calcium carbonate (CCE), active calcium carbonate (ACCE), and N:P ratio ($P < 0.001$ and $P < 0.05$). However, nitrogen and salinity negatively influenced oil production ($P < 0.001$). The C:N ratio did not show any significant effect (Fig. 3; Table 2). The amount of EOs in *T. algeriensis* appeared positively correlated with salinity, pH, and N:P ratio ($P < 0.001$) and negatively with CCE, ACCE, and carbon ($P < 0.001$) (Fig. 3; Table 2).

Both total CCE and active ACCE exhibited a positive effect on EO production in *R. officinalis* and a negative impact in *T. algeriensis*. According to the literature, *R. officinalis* grows spontaneously on calcareous hills (Wichtl and Anton 2003; Beloued 2005) and *T. algeriensis* grows wild in lawns and rockeries (Beloued 2005). These two antagonistic effects on the two plants may be attributed to the physiological responses of each species to the amount of calcium carbonate,

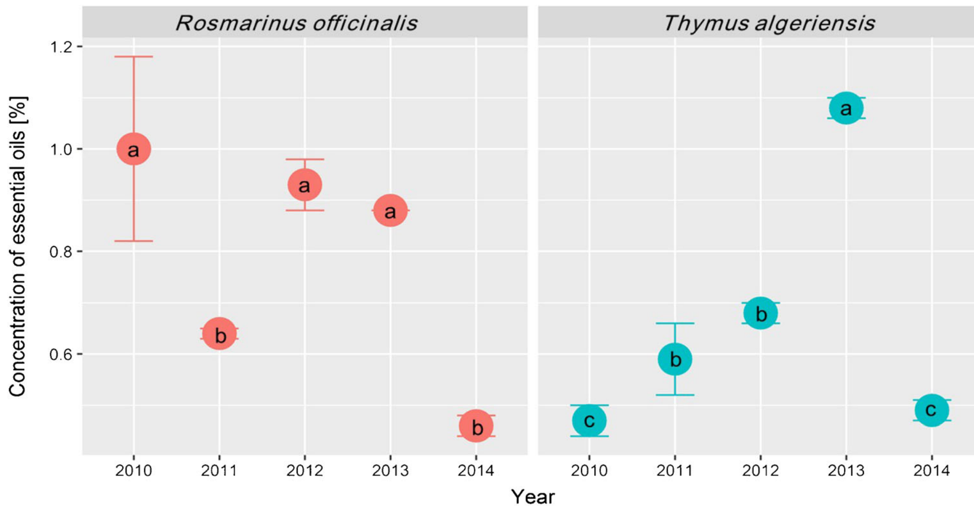

Fig. 2 Yields of essential oils in *R. officinalis* and *T. algeriensis* accumulated during the years 2010–2014

notably that the soil was found to be moderately calcareous (see Table 1). Calcium is considered a secondary messenger in certain responses to environmental factors and could be an important factor in regulating the activities of many enzymes (Hopkins 2003). In regions with arid and semiarid climate, Lamiaceae plants yield higher EOs on calcareous soil than on sandy soil. This corroborates our results, as for the CCE and ACCE which were obtained with significantly positive influences on the quantity of EOs of *R. officinalis*, which occurs mainly in association with forest and sub-forest vegetation in mountains with calcareous substrate. Conversely, EO yields of *T. algeriensis* were negatively influenced by CCE and ACCE. Thus, in regard to the two plant species studied, our findings suggest that *R. officinalis* behaved as a calcicole species, whereas *T. algeriensis* behaved as a calcifuge species. Likewise, the chemical quality of essential oils is influenced by the characteristics of the soil (Aboukhalid et al. 2017). For example, Aziz et al. (2008) and Said-Al Ahl et al. (2019) reported that the production of some EO major compounds by *Thymus vulgaris* was greater when this plant grew in sandy soil and less in clay soil; however, the calcareous soil gave an intermediate proportion.

Our results indicated that total nitrogen and organic carbon negatively affected the content of essential oils in *R. officinalis* and *T. algeriensis* respectively. In fact, the plant incorporates inorganic carbon (atmospheric CO_2) or mineral forms of carbon dissolved in the soil solution to synthesize organic molecules. Likewise, the plant absorbs mineral forms of nitrogen (NO_3^-, NH_4^+). The observed negative correlations can be explained by a lack of mineral forms of carbon and nitrogen in the soil solution, and this may be attributed to the conditions of degradation and mineralization of organic matter. In addition, the non-significant effect of C:N ratio on the target plants revealed that the complex organic matter had no influence on the oil production. On the other hand, the plant obtains carbon from carbon dioxide (CO_2) and from mineral forms existing in the soil solution. Inorganic carbon is essential for the production of carbohydrates by photosynthesis (Weil 1998; Hopkins 2003). Moreover, carbohydrates are main precursors of most secondary metabolites such as phenolic compounds via the shikimic acid pathway. Carbohydrate derivatives such as acetyl CoA are used in the synthesis of terpene compounds via the mevalonic acid pathway (Weil 1998; Hopkins 2003; Bhatla 2018). In fact, phenolic acids and terpene compounds, in particular monoterpenes and sesquiterpenes, are the main compounds of essential oils (Nikolić et al. 2014; Mehalaine et al. 2017; Bhatla 2018). Nitrogen is a constituent of many important molecules such as proteins, nucleic acids, and chlorophyll (Hopkins 2003). According to these data, an appropriate carbon and nitrogen nutrition leads to a good assimilation of volatile compounds. Singh et al. (2016) reported that the nitrogen fertilization improved oil yield in *Zingiber officinale* and this is due to the positive effect of nitrogen on biomass and photosynthesis. However, the concentration of certain oil molecules in *Heracleum persicum* was found to be increased in soil with a low content of nitrogen and richness in salts (Hasani et al. 2017). According to Vaičiulytė et al. (2017), the increase of some micronutrient or macronutrient content in the soil may promote a decrease or increase in the main compounds and EO quantity of *Thymus pulegioides.*

In this work, the findings showed that the pH and N:P ratio had positive effects on the concentration of essential oils in both species. It appeared that the two elements, nitrogen and phosphorus, exerted their synergistic effect on the assimilation of primary metabolites and consequently the secondary metabolites. In addition, soil pH plays a major role in the availability of mineral phosphorus and its absorption by plant roots (Hopkins 2003). Phosphorus is found in phosphorylated carbohydrates which play an extremely important role in photosynthesis and intermediate metabolism. This element also plays a central role in the energy metabolism of cells (Hopkins 2003). The phosphorus content positively affected the oil yield in *Heracleum persicum* (Hasani et al. 2017). Jeshni et al. (2017) reported that the

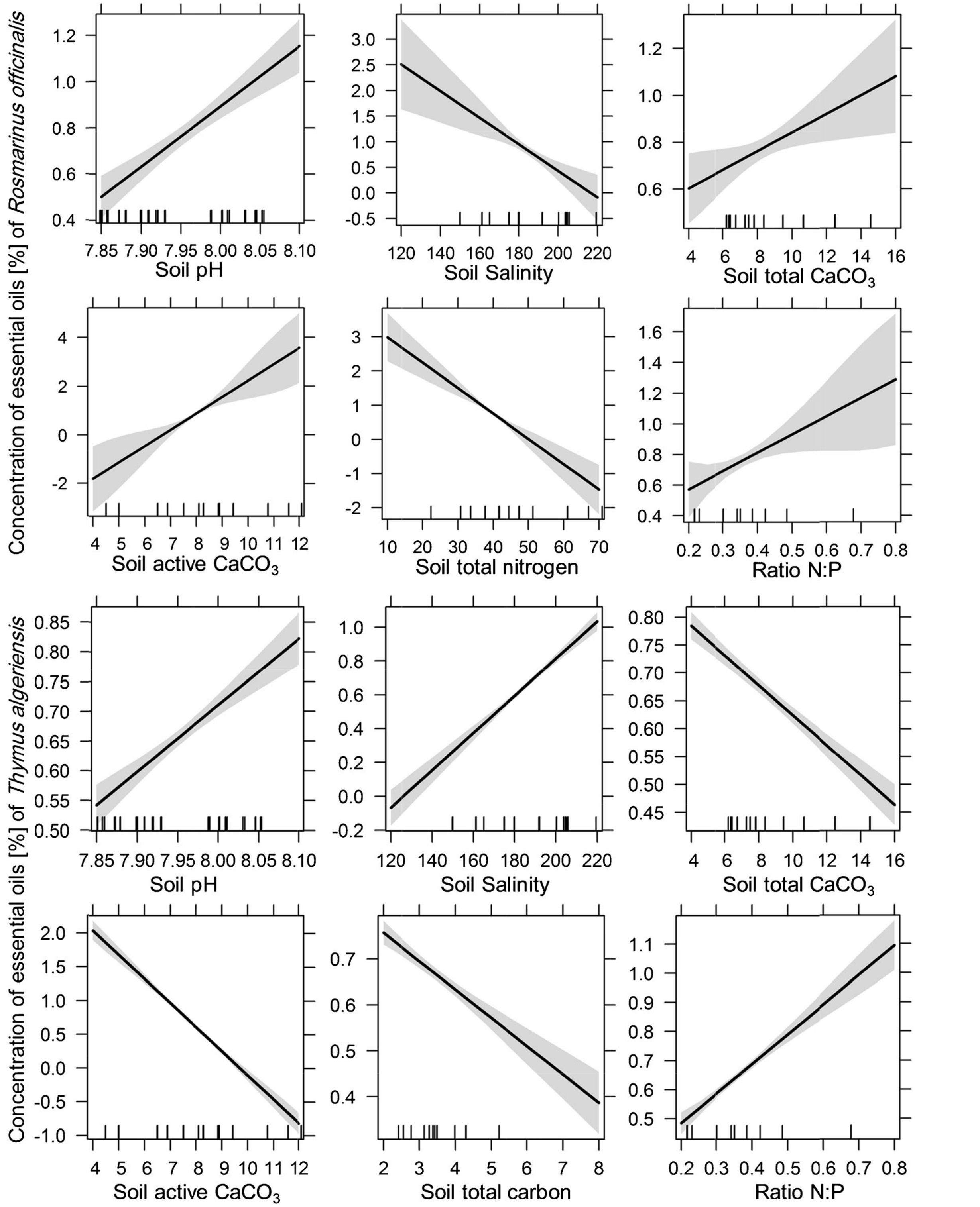

Fig. 3 Effect plots associated to significant terms of the GLM (Table 2) testing the effects of soil properties on the variation of EO production in *Rosmarinus officinalis* and *Thymus algeriensis* growing wild in semiarid lands of Algeria

application of optimal doses of phosphorus improved the yield of essential oils in *Matricaria recutita*. The presence of high content of soluble phosphorus in the soil can positively affect biosynthesis of some EO compounds (Vaičiulytė et al. 2017).

Our data showed that salinity parameter negatively affected *R. officinalis* oil concentration and positively affected that of *T. algeriensis*. Razmjoo et al. (2008) found that the increased salinity promoted reduction in plant biomass and therefore a

Table 2 Generalized linear models (Gaussian distribution and Identity link) testing the impact of the chemical parameters of the soil on the accumulation of essential oils in *Rosmarinus officinalis* and *Thymus algeriensis* growing wild in semiarid regions of Algeria. Parameters of each GLM were obtained using the "backward/forward" stepwise selection procedure based on the lowest Akaike information criterion (AIC) value

Parameters	Estimate	2.5% CI	97.5% CI	Std. error	*t* value	*P*	Sig.
Rosmarinus officinalis (AIC = − 43.087, ΔAIC = 2.01)							
(Intercept)	− 18.225	− 23.875	− 12.574	2.883	− 6.321	< 0.001	***
pH	2.615	1.875	3.355	0.378	6.925	< 0.001	***
Salinity	− 0.026	− 0.039	− 0.013	0.007	− 3.987	< 0.001	***
CCE	0.040	0.009	0.071	0.016	2.545	0.015	*
ACCE	0.672	0.338	1.007	0.171	3.939	< 0.001	***
Nitrogen	− 0.074	− 0.097	− 0.051	0.012	− 6.327	< 0.001	***
N:P ratio	1.201	0.229	2.173	0.496	2.422	0.020	*
C:N ratio	− 0.487	− 1.029	0.055	0.276	− 1.762	0.086	NS
Thymus algeriensis (AIC = − 149.23, ΔAIC = 2.33)							
(Intercept)	− 7.430	− 9.650	− 5.210	1.133	− 6.560	< 0.001	***
pH	1.121	0.834	1.407	0.146	7.659	< 0.001	***
Salinity	0.011	0.009	0.013	0.001	14.077	< 0.001	***
CCE	− 0.027	− 0.031	− 0.022	0.002	− 11.805	< 0.001	***
ACCE	− 0.358	− 0.394	− 0.322	0.018	− 19.594	< 0.001	***
Carbon	− 0.062	− 0.076	− 0.047	0.007	− 8.410	< 0.001	***
N:P ratio	1.015	0.822	1.208	0.098	10.316	< 0.001	***

ΔAIC = AIC difference between the full GLM (see Appendix Table 3) and the simplified model with the lowest AIC based on "backward/forward" stepwise selection procedure. *2.5% CI* and *97.5% CI*, lower and upper limits of confidence interval (CI), respectively; *Std. error*, standard error; *P*, *P* value; *Sig.*, statistical significance. ***$P < 0.001$, *$P \leq 0.05$, ^{NS} $P > 0.05$

decrease of EO quantity in *Matricaria chamomile*. According to Hasani et al. (2017), the electrical conductivity negatively affected the number of EO compounds in *Heracleum persicum* and it can positively or negatively affect the oil chemical profile. However, Baghalian et al. (2008) reported that the saline irrigation water did not affect the quantity and quality of EOs in *Matricaria recutita*. According to this literature, the tolerance and adaptation mechanism to salinity differ from plant species to another.

Extreme and stressful ecological conditions such as salinity, drought, and mineral salt excess affect the production of EOs in plants (Razmjoo et al. 2008; Niinemets et al. 2013; Bhatla 2018). In some cases, stressed plants are induced to modify the quantity and quality of their secondary metabolites such as phenolic compounds and essential oils to cope and adapt (Jeshni et al. 2017; Bhatla 2018). Thus, it is possible to manipulate certain soil chemical parameters to induce a plant stress in order to modify the quality and yield of essential oils.

Conclusions

This present study was an attempt to examine the effect of soil chemical parameters on the assimilation and quantity of essential oils in *R. officinalis* and *T. algeriensis* growing wild in Algerian semiarid area during a long period. The results indicated significant differences between the yearly EO yields in both plants. The results also showed that the characterized soil variables significantly influenced the EO yield in both plants. *R. officinalis* EO content was found to be positively influenced by pH, total $CaCO_3$, active $CaCO_3$, and N:P ratio. *Thymus algeriensis* EO amount appeared positively affected by pH, salinity, and N:P ratio. The obtained findings do not make it possible to give very precise explanations at the physiological level of plants with regard to their mineral nutrition. But, they allow to understand how these plants adapt and respond to these characterized edaphic conditions through the assimilated quantities of essential oils, in particular that they are two aromatic plants. The data also help to develop an effective protocol of mineral nutrition for each species under controlled experimental conditions. In our later study, we will confirm our results by growing these plants on liquid nutrient medium or hydroponic culture where the plants will grow on well-defined nutrient solutions and provide more reliable results.

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Authors' contributions SM and HC conceived the ideas of the study. SM designed methodology and conducted field and laboratory works. HC analyzed data and designed the article. SM and HC drafted, revised the manuscript, and approved the final version of the article.

Data availability The datasets used and/or analyzed during the current study are available from the authors on reasonable request.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix

Table 3 Summaries of full generalized linear models (GLMs) obtained prior to model simplification and selection using "stepwise" method and "backward/forward" direction and based on Akaike information criterion (AIC) values. Each GLM tested the variation of EOs for each plant species separately

Parameters	Estimate	2.5% CI	97.5% CI	Std. error	*t* value	*P* value	Sig.
Rosmarinus officinalis (AIC = − 41.08)							
(Intercept)	− 18.373	− 25.787	− 10.959	3.783	− 4.857	< 0.001	***
pH	2.633	1.683	3.584	0.485	5.432	< 0.001	***
Salinity	− 0.026	− 0.043	− 0.009	0.009	− 2.980	0.005	**
CCE	0.039	0.000	0.078	0.020	1.956	0.058	NS
ACCE	0.663	0.208	1.118	0.232	2.855	0.007	**
Carbon	− 0.002	− 0.070	0.066	0.035	− 0.062	0.951	NS
Nitrogen	− 0.073	− 0.107	− 0.040	0.017	− 4.288	< 0.001	***
C:N ratio	− 0.482	− 1.051	0.086	0.290	− 1.663	0.105	NS
N:P ratio	1.192	0.164	2.219	0.524	2.273	0.029	*
Thymus algeriensis (AIC = − 146.90)							
(Intercept)	− 7.661	− 9.949	− 5.373	1.167	− 6.563	< 0.001	***
pH	1.148	0.854	1.441	0.150	7.670	< 0.001	***
Salinity	0.014	0.009	0.019	0.003	5.175	< 0.001	***
CCE	− 0.033	− 0.045	− 0.021	0.006	− 5.396	< 0.001	***
ACCE	− 0.432	− 0.573	− 0.292	0.072	− 6.033	< 0.001	***
Carbon	− 0.067	− 0.088	− 0.047	0.011	− 6.320	< 0.001	***
Nitrogen	0.004	− 0.007	0.014	0.005	0.698	0.490	NS
C:N ratio	− 0.050	− 0.225	0.125	0.090	− 0.558	0.580	NS
N:P ratio	1.081	0.764	1.398	0.162	6.679	< 0.001	***

2.5% *CI* and 97.5% *CI*, lower and upper limits of confidence interval (CI), respectively; *Std. error*, standard error; *Sig.*, statistical significance. ***$P < 0.001$, **$P < 0.01$, *$P \leq 0.05$, ^{NS} $P > 0.05$

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