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# Effect of soil type on growth, productivity, and essential oil constituents of rosemary, *Rosmarinus officinalis*

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## Abstract

Rosemary, *Rosmarinus officinalis* L., is a remarkable medicinal plant containing number of phytochemicals with pharmaceutical and flavoring uses. As part of development of agro technology package of practices for large scale cultivation of rosemary, experiments were designed to examine the influence of soil texture using different ratios of sand and loam soil.

Pot experiments were conducted at the Experimental Station of National Research Centre during 2015 and 2016 successive seasons. To determine the best soil texture and type for rosemary cultivation, seven different combinations of sand: loam (100:0, 75:25, 66.75: 33.25, 50:50, 33.25:66.75, 25:75, and 0:100) were filled in 30cm pots where shoot tip cuttings of rosemary were planted.

All growth characters such as plant height, number of branches, herb fresh and herb dry weight were measured. Maximum values were recorded in 100% loam soil comparing with other soil types. Essential oil yield was also higher in 100% loam soil compared to others. Results showed that soil types had a pronounced effect on chemical constitutions of essential oil with higher major constitutions, camphor and α-pinene, under sand soil.

These results suggest cultivation of rosemary in loamy soil for higher productivity as well as in sandy soil for higher quality.

**Keywords:** *Rosmarinus officinalis*, Essential oil, Sandy soil, Loamy soil, Camphor

## Introduction

Medicinal and aromatic plants represent an important source of income in agriculture section of national economy in many countries (Adhikari, 2001). These plants are the main source of the drugs. Rosemary plant (*Rosmarinus officinalis* L.) is an influential medicinal perennial herb used externally as parasiticide and cicatrizing for muscular pains and rheumatism, dermatitis, dandruff, and eczema (González-Trujano et al., 2007 ). It is used for flavor, cosmetic, and traditional medicine for choretics, hepatoprotective, and antimorigenic activity (Slamenova et al., 2002). Therefore, Rosemary extracts have great interest for food industries as a source of active compound and medicine as a great part of drugs.

There are a few basic resources which greatly determine plant life on earth. These resources include light, carbon dioxide ($CO_2$), water, and mineral nutrients. Plants observe light from the sun, and $CO_2$ are generally abundant and distributed throughout the atmosphere. While plant observe water and mineral nutrients from the growth media, soil. Water and mineral nutrients are important resources that can limit plant growth and survival. Although the availability of water and nutrients for plants is determined by several factors such as regional and local climate, the main limiting factor is soil, a resource that must be conserved and managed with increasing care. Soil and nutritive requirements of plants vary greatly among species. Enormous studies have reported the effects on plants growth and quality by mineral nutrients, drought, light intensity and altitude (Lebaschi and Sharifi, 2004; Ardakani et al., 2007; Ardakani and Mafakheri, 2011). However, the aspect of soil type effects had not received suitable concerning for most medicinal plants. The soils mainly characterized with physical, chemical, and microbiological properties. The balance in the soil pores between air and water greatly effects on plant growth. The pores are important in aeration of soil, movement of water, availability of plant nutrient, and activity of microorganisms (Metwally et al., 1972; Abou-Leila et al., 1993). Sandy clay soil suggested for supporting the greatest growth and essential oil yield of *Mentha arvensis* (Kahkashan et al., 2016). When comparing *Artemisia Annua* L. plants under clay loamy and sand loamy soils, higher vegetative growth characters were obtained under clay loamy soil (Omer et al., 2013). Higher essential oil content was observed under sand loamy soil, while higher essential oil yield observed under clay loamy soil. The soil type influenced on the order of the followed compounds.

Therefore the current study was aimed to identify the suitable soil condition for better growth, herb productivity, and essential oil of *Rosmarinus officinalis*. Sandy and loamy soils were selected and mixed in different ratios. This study will help growers to select the suitable soil type for rosemary cultivation.

## Materials and Methods

**Soil sample preparation and plant cultivation:**

This study was achieved in a greenhouse during 2015 and 2016 successive seasons at the National Research Centre, Cairo, Egypt. Sand and loam soils were collected and prepared. Preparation procedure involved air drying, grinding, sieving, mixing and partitioning. Pot experiment was designed to test the effect of different soil mixtures (w/w) as following: $T_1$ (100% sand: 0 % loam), T2 (75% sand: 25 % loam), T3 (66.75% sand: 33.25 % loam), T4 (50% sand: 50 % loam), T5 (33.25% sand: 66.75 % loam), T6 (25% sand: 75 % loam), and T7 (0% sand: 100 % loam).

Rosemary seedlings were cultivated on March 20$^{th}$ during two successive seasons into plastic pots. Pot size was 30×50 cm (diameter and height), and was filled out with air-dried mixed soil (10 kg). The plants were harvested twice during the both growing seasons, after 70 and 140 days from cultivation. Harvest was done by snipping the plants above the soil surface by 5 cm. Plant height (cm), number of branches per plant, herb fresh, and dry mass were measured at each cut.

**Essential oil extraction and GC/MS analysis:** During the first and second harvest, fresh shoots were collected from each treatment. The fresh shoot (300g) was hydro-distillated using Clevenger-type apparatus for three hours (Clevenger, 1928). Then, essential oil content (%) and total essential oil yield per plant were calculated according to the fresh weight. Then the extracted essential oils have been collected and dried using anhydrous sodium sulphate for chemical constituents' identification.

GC-MS analysis has been done at Department of Medicinal and Aromatic Plants Research, National Research Center, for both cuts of the second season using Gas Chromatography–Mass Spectrometry (THERMO Scientific Corp., USA), coupled with a THERMO mass spectrometer detector (ISQ Single Quadrupole Mass Spectrometer). The GC Mass system was equipped with a TG-WAX MS column (30m m × 0.25 mm i.d., film thickness of 0.25 $\mu$m). Helium has been used as a carrier gas, and the analyses were done using 1.0 mL/min flow rate and 1:10 split ratio. The temperature programming adjusted at 40°C for 1 min, increased by 4.0°C/min up to 160°C, kept stable for 6 min, increased again by 6°C/min up to 210°C, and kept stable for 1 min. Both injector and detector were kept stable at 210°C. Samples were diluted with hexane (1:10) and 0.2 $\mu$L of the dilutions have been injected. Mass spectra were obtained using electron ionization (EI) at 70 eV, with a m/z 40-450 spectral. Mostly, the constitutions were identified using mass spectra (Wiley spectral library collection and NIST library). The essential oil constituents were determined by matching with the National Institute of Standards and Technology published data (Adams, 2007).

**Statistical analysis:**

The experimental design followed One way Randomized Blocks according to Snedecor and

Cochran (1980). One factor was considered in this experiment which was soil ratios and each treatment contained three replicates, each replicate comprised 10 pots; three individual plants were cultivated in each pot.

## Results and Discussion

**Characters of growth:**
The analysis of growth characters (plant height, number of branches, and herb fresh and dry weight) of *Rosmarinus officinalis* L. revealed that there are significant differences between these characters except number of branches/plant during 2$^{nd}$ cut (Tables 1 and 2). During the 1$^{st}$ cut, 100% loam soil (T7) gave the highest plant height (40.50 cm), while 100% sand soil (T1) gave the lowest one (29.67 cm). For number of branches/plant, 100% loam soil produced the maximum mean value of number of branches (10.38) followed by (25% sand: 75% loam) which gave (10.09). The lowest mean value of number of branches/plant (7.25) was obtained as a result of 100% sand soil. Average fresh and dry weights of herb (g/plant) were significantly differed due to different soil ratios which used in the experiment. The heaviest herb fresh and dry weight (50.88 and 23.38 g/plant, respectively) were observed under 100% loam soil compared to other treatments. The lowest mean values of herb fresh and dry weights were produced from plants cultivated in sand soil without loam soil (100% sand: 0% loam) which recorded 39.48 and 15.55 g/plant, respectively. During the 2$^{nd}$ cut the same trend as mentioned with 1$^{st}$ cut was observed. Soil mixture (100% loam) gave the highest mean values for all growth characters under study. Within the different soil conditions *Rosmarinus officinalis* responded in different manner. It gave better growth pattern for the soil ratio of 100% loam.
Soil type is an influential factors limiting plant growth, productivity, and biochemical constitutions (Kahkashan et al., 2016). Loam is a fertile soil composed of roughly two-fifth sand, two-fifth silt, and one-fifth clay. It combines the best qualities of each of the four soil types, making it a medium that almost any type of plant can thrive in. Moisture and nutrients flow freely around the plant because the soil is composed of different particle sizes. Almost all plants do well in a loamy soil, but some agricultural crops require a loamy soil for success. Dark, moist and porous nature of loam offers good drainage. Often, plants dwelling in soils that effectively retain and drain water are healthy and productive. The natural elements in loamy soil make it the most suitable for lifetime partner of a healthy plant ecosystem. These natural elements consist of bacteria, fungi and earthworms. These organic soil dwellers when combined act as decomposers breaking down plant and animal tissue to form humus. Humus inhibits roots growth and effectively retains water and air. The sand soils group consists of at least 70% sand. The clay soil group consists of at least 35-40% clay. The loamy soil consists of sand, silt, and clay particles mixture that exhibit equal proportions of light and heavy properties. Therefore, the loam soil group begins from this point and then contains more or less amounts of sand, silt, or clay particles. Sand has large particles with very small exposed surface specific area (0.1 $m^2/g$). These are fractions of quartz which is insoluble (ability to supply nutrients is practically nil). The intermediate spaces are greater (macro pores) facilitating rapidly movement of air and water. Sand has low water absorption ability, and does not exhibit swelling, shrinkages, stickiness, and plasticity properties. Also, sand does not display properties of cohesions, moisture, nutrient retention, etc unless overlaying with clay or silt. Sandy soils have low water holding capacity, low fertile, and quickly dry out. It can be easily planted with less draft requirements. Sand particles are coarse and large, and therefore sandy soils are called as coarse textured or light soils. Soil texture is the main factor determining the chemical and physical characterizations of soil such as water holding capacity, nutrient reservation, drainage, strength, and thermal properties. Suitable soil to a special crop depends on its texture, depth, level of water table, salinity, and alkalinity. Loamy soils have intermediate properties; retain more water and nutrients comparing to sandy soil, and have better drainage, aeration and tillage properties comparing to clay soils. Therefore, Loamy soils are considered the best for agricultural production.

**Essential oil percentage (%) and yield (ml/plant):**
Mean values of essential oil percentage (%) and yield (ml/plant) as influenced by different soil ratios are shown in Table (3). It was noticed that soil ratios did not affect significantly on essential oil content during both cuts. The highest essential oil content (1.24% and 1.41% for both cuts, respectively) were obtained as a result of soil ratios (25% sand: 75% loam) and (sand 0%: loam 100%), respectively. Concerning the effect of soil types ratios, these soil ratios significantly

affected on essential oil yield (ml/plant) during both cuts. During the 1st cut, soil ratio (25% sand: 75% loam) led to the maximum essential oil yield (0.578 ml/plant) followed by (0% sand: 100% loam) which gave (0.509 ml/plant). In the 2nd cut, the maximum value of oil yield (0.750 ml/plant) was observed under 100 % loam soil, followed by soil ratio (25% sand: 75% loam) which recorded (0.634 ml/plant). The lowest values of essential oil yield were observed under 100% sand soil which produced 0.355 and 0.285 ml/plant in 1st and 2nd cut, respectively. The increases of essential oil yield per plant may be a result of increasing herb fresh weight or/and increasing essential oil content (%).

**Table - 1: Influence of soil types on growth characters of Rosmarinus officinalis L. during 1st cut. The data represent mean values of the two successive seasons and differences according to Tukey.**

| Soil type | Plant height (cm) | Number of branches | Herb fresh weight (g/plant) | Herb dry weight (g/plant) |
|---|---|---|---|---|
| T1 (100% Sand: 0 % loam) | $29.67^{d}$ | $7.25^{b}$ | $39.48^{c}$ | $15.55^{c}$ |
| T2 (75% Sand: 25 % loam) | $30.50^{d}$ | $7.90^{ab}$ | $40.30^{c}$ | $15.92^{c}$ |
| T3 (66.75% Sand: 33.25 % loam) | $31.75^{d}$ | $8.30^{ab}$ | $39.60^{c}$ | $16.89^{c}$ |
| T4 (50% Sand: 50 % loam) | $34.50^{c}$ | $9.05^{ab}$ | $41.75^{c}$ | $17.30^{c}$ |
| T5 (33.25% Sand: 66.75 % loam) | $35.13^{c}$ | $8.85^{ab}$ | $45.73^{b}$ | $17.79^{c}$ |
| T6 (25% Sand: 75 % loam) | $37.75^{b}$ | $10.09^{a}$ | $46.63^{b}$ | $20.53^{b}$ |
| T7 (0% Sand: 100 % loam) | $40.50^{a}$ | $10.38^{a}$ | $50.88^{a}$ | $23.38^{a}$ |

**Table - 2: Influence of soil types on growth characters of Rosmarinus officinalis L. during 2nd cut. The data represent mean values of the two successive seasons and differences according to Tukey.**

| Soil type | Plant height (cm) | Number of branches | Herb fresh weight (g/plant) | Herb dry weight (g/plant) |
|---|---|---|---|---|
| T1 (100% Sand: 0 % loam) | $33.00^{d}$ | $9.03^{a}$ | $28.83^{d}$ | $11.45^{d}$ |
| T2 (75% Sand: 25 % loam) | $36.00^{c}$ | $9.50^{a}$ | $33.67^{c}$ | $12.05^{d}$ |
| T3 (66.75% Sand: 33.25 % loam) | $36.57^{c}$ | $9.63^{a}$ | $34.75^{c}$ | $13.20^{cd}$ |
| T4 (50% Sand: 50 % loam) | $38.00^{c}$ | $10.30^{a}$ | $34.73^{c}$ | $14.92^{c}$ |
| T5 (33.25% Sand: 66.75 % loam) | $42.00^{b}$ | $9.03^{a}$ | $40.07^{b}$ | $14.99^{c}$ |
| T6 (25% Sand: 75 % loam) | $45.00^{a}$ | $11.03^{a}$ | $52.90^{a}$ | $23.28^{b}$ |
| T7 (0% Sand: 100 % loam) | $46.00^{a}$ | $11.43^{a}$ | $53.17^{a}$ | $29.77^{a}$ |

**Table - 3: Influence of soil types on essential oil content (%) and yield (ml/plant) of Rosmarinus officinalis L. The data represent mean values of the two successive seasons and differences according to Tukey.**

| Soil type | Essential oil (%) | | Essential oil yield (ml/plant) | |
|---|---|---|---|---|
| | 1st cut | 2nd cut | 1st cut | 2nd cut |
| T1 (100% Sand: 0 % loam) | $0.90^{a}$ | $0.99^{a}$ | $0.355^{g}$ | $0.285^{g}$ |
| T2 (75% Sand: 25 % loam) | $0.90^{a}$ | $0.99^{a}$ | $0.363^{f}$ | $0.333^{f}$ |
| T3 (66.75% Sand: 33.25 % loam) | $0.93^{a}$ | $1.19^{a}$ | $0.368^{e}$ | $0.414^{d}$ |
| T4 (50% Sand: 50 % loam) | $0.98^{a}$ | $1.06^{a}$ | $0.409^{d}$ | $0.368^{e}$ |
| T5 (33.25% Sand: 66.75 % loam) | $1.03^{a}$ | $1.10^{a}$ | $0.471^{c}$ | $0.441^{c}$ |
| T6 (25% Sand: 75 % loam) | $1.24^{a}$ | $1.20^{a}$ | $0.578^{a}$ | $0.634^{b}$ |
| T7 (0% Sand: 100 % loam) | $1.00^{a}$ | $1.41^{a}$ | $0.509^{b}$ | $0.750^{a}$ |

**Essential oil constituents:**

The effects of soil ratios on the essential oil constituents of rosemary, *Rosmarinus officinalis* L., were shown in Table (4). The GC/MS analysis identified the main compound as camphor (28.27 to 32.36% of the total constituents) followed by α-pinene (13.28-18.82%), Eucalyptol, 1,8-cineole, (12.77-15.79 %), and Camphene (5.85 to 7.96 %). In this respect, Dellacassa et al. (1999) investigated essential oil composition of rosemary cultivars growing in different regions of Brazil and Uruguay. They found that the major components of essential oil in Uruguay plants were α-pinene (37.8–46.2%) and 1,8-cineole (13.4–13.8%), while the major components in Brazilian cultivated plants were α-pinene and 1,8-cineole (32.2%, and 14.7%, respectively), and in wild Brazilian plants were α-pinene, myrcene, and 1,8-cineole (12.4%, 22.7%, and 15.3%, respectively). In Rio de Janeiro, Brazil, Porte et al. (2000) isolated and analyzed the essential oil from rosemary fresh leaves and they identified 36-45 constituents. The major components of the essential oil were camphor, 1,8-cineole, myrcene, and α-pinene (26.0%, 22.1%, 12.4%, and 11.5%, respectively). It was confirmed that the geographical location contribute mainly to the essential oil content and quality (Guillén et al., 1996). It is reported that essential oil of rosemary plant distinguished with richer flavor and higher complexity oils in some Spanish rosemary oils than others. Differences in percentages of α-pinene,1,8-cineole, camphor, verbenone and linalool comparing to essential oils from different geo-graphical regions were observed. Tomei et al. (1995) analyzed flowers and leaves essential oil of wild rosemary plants from southern Spain; It was reported that the major components were camphor, 1,8-cineole, and α-pinene (32.33%, 14.41%, and 11.56%, respectively). Chalchat el al. (1993) analyzed the essential oils of Spanish Rosemary and found that it is rich in α-pinene, 1,8-cineole, and camphor (24.7%, 21.8%, and 18.9%, respectively) in addition to borneol (4.5%). These findings are in consistent with the results obtained from our study. Comparative study of the essential oils was carried out using some plants collected from Giza and Sinai (Soliman et al., 1994). GC-MS analysis of the oils identified 43 different components in the sample collected from Sinai, and the major components were verbenone, camphor, bornyl acetate, and limonene (12.3%, 11.3%, 7.6%, and 7.1%, respectively). On the other hand, 37 components were identified in the sample collected from Giza, and the major components were camphor, α-pinene, as well as 1,8-cineole (14.9%, 9.3%, and 9.0%, respectively). In Algeria, Boutekedjir et al. (1998) analyzed the essential oil of flowering aerial parts of rosemary and determined more than 90% of the components. Major components were 1,8-cineole and camphor (52.4% and 12.6%, respectively). Another study on Algerian rosemary showed that the major components included camphor, borneol, bornyl acetate, α-humulene, α-terpineol, β-caryophyllene, δ-cadinene, and muurolene (Benhabiles et al., 2001).

Data in Table (4) showed that total identified compounds ranged from 99.86 to 100%. The total amount of monoterpene hydrocarbons ranged from 36.67 to 42.52%, while total oxygenated monoterpene ranged from 56.95 to 63.10% in the identified compound. Moreover, sesquiterpene hydrocarbons ranged from 0.20 to 0.54%. The minimum percentage of monoterpene hydrocarbons (36.67%) was observed with soil ratio (50% sand: 50% loam), while the maximum percentage was produced from soil ratio (66.75% sand: 33.25% loam). The minimum percentage of total oxygenated monoterpenes compounds was observed from soil ratio (66.75% sand: 33.25% loam), while soil ratio (75% sand: 25% loam) gave the maximum one.

The results of this study showed great variability in the essential oils composition obtained from species under different soil type. The variability in chemical components depends on several environmental factors such as climate, time in the year, location, soil properties, the plant part, and the extraction technique from essential oil. The mean values of main compounds indicated that soil ratio (100% sand) resulted in the maximum mean value of camphor, while soil ratio (66.75% sand: 33.35% loam) gave the lowest mean value (28.27%). The second main compound namely α-pinene was also identified in essential oil of all treatment. Also, soil ratio (100% sand) gave the highest relative percentage of α-pinene (18.82%) followed by soil ratio (100% loam) which recorded (15.71%), while the lowest value of this compound (13.28%) was obtained as a result of soil ratio (25% sand: 75% loam). Eucalyptol was reported as the third major component of the essential oil under all treatments. Soil ratio (75% sand: 255 loam) produced the highest relative percentage of eucalyptol (15.79%) followed by (50% sand: 50% loam) which gave (15.51%). On the other hand, soil ratio (25% sand: 75% loam) produced the lowest relative percentage of eucalyptol (13.84%). Camphene was the fourth major component in the essential oil under all treatments. The maximum relative percentage of camphene (7.96%) was obtained as a result of soil ratio (66.75% sand: 33.35% loam) against soil ratio (100% sand) which gave the lowest one (4.54%).

**Table - 4: Influence of soil types on essential oil constituents of Rosmarinus officinalis L. during 2nd cut of 2nd season**

| Compounds | Rt | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|---|
| Tricyclene | 3.70 | -- | 0.20 | 0.27 | 0.21 | 0.22 | 0.27 | 0.23 |
| α-pinene | 3.91 | 18.82 | 15.32 | 15.67 | 14.49 | 14.11 | 13.28 | 15.71 |
| camphene | 4.54 | 5.85 | 7.18 | 7.96 | 7.07 | 7.40 | 7.64 | 7.68 |
| β-pinene | 5.25 | 0.95 | 1.63 | 2.96 | 1.20 | 1.24 | 1.62 | 1.63 |
| Sabinyl acetate | 5.37 | 0.47 | -- | -- | -- | -- | -- | -- |
| 2,4(10)-thujadien | 5.63 | -- | 0.44 | 0.48 | 0.49 | 0.52 | 0.64 | 0.53 |
| α-phellandrene | 6.53 | 0.21 | 0.22 | 0.38 | 0.21 | 0.23 | 0.30 | 0.29 |
| β- myrcene | 6.63 | 1.24 | 1.34 | 1.88 | 1.46 | 1.57 | 1.73 | 1.68 |
| α-terpinene | 6.88 | 0.62 | 0.70 | 1.09 | 0.68 | 0.73 | 0.93 | 0.88 |
| d-limonene | 7.34 | 5.62 | 5.11 | 5.94 | 5.44 | 5.88 | 6.62 | 6.24 |
| eucalyptol | 7.66 | 14.00 | 15.79 | 12.77 | 15.51 | 15.02 | 13.84 | 14.06 |
| γ-terpinene | 8.58 | 1.09 | 1.46 | 2.46 | 1.22 | 1.26 | 1.63 | 1.68 |
| o-cymene | 9.35 | 2.66 | 2.20 | 1.24 | 2.89 | 3.17 | 3.21 | 2.55 |
| α-terpinolene | 9.59 | 1.12 | 1.21 | 2.19 | 1.15 | 1.10 | 1.42 | 1.68 |
| p-cymenene | 14.49 | -- | -- | -- | 0.16 | 0.18 | 0.21 | -- |
| Trans-sabinene hydrate | 15.59 | -- | -- | 0.26 | -- | -- | -- | -- |
| α-campholenal | 16.22 | 0.31 | 0.37 | 0.41 | 0.38 | 0.39 | 0.44 | 0.34 |
| chrysanthenone | 16.71 | -- | -- | -- | -- | 0.21 | -- | -- |
| camphor | 16.98 | 32.36 | 31.72 | 28.27 | 31.28 | 29.75 | 28.28 | 29.33 |
| α-pinene oxide | 17.33 | -- | -- | 0.19 | 0.15 | -- | 0.19 | 0.14 |
| Isocamphopinon | 17.80 | 0.14 | 0.16 | 0.22 | 0.18 | 0.18 | 0.24 | 0.18 |
| linalool | 18.18 | 1.11 | 1.45 | 1.80 | 1.56 | 1.63 | 2.00 | 1.45 |
| Pinocarvone | 18.51 | 0.31 | 0.33 | 0.35 | 0.38 | 0.40 | 0.46 | 0.35 |
| Bornyl acetate | 18.77 | -- | 0.25 | 0.52 | -- | -- | 0.19 | 0.16 |
| Trans-caryophyllene | 18.96 | 0.18 | 0.16 | 0.23 | -- | -- | 0.20 | 0.17 |
| Terpinen-4-ol | 19.68 | 0.96 | 1.15 | 1.20 | 1.36 | 1.37 | 1.48 | 1.22 |
| α- caryophyllene | 21.11 | 0.28 | 0.23 | 0.31 | 0.20 | 0.23 | 0.25 | 0.23 |
| α-terpineol | 21.82 | 0.16 | 0.18 | --- | 0.22 | 0.23 | 0.23 | 0.18 |
| Cis-verbenol | 21.99 | 0.15 | 0.16 | 0.24 | --- | 0.18 | -- | 0.15 |
| β-fenchyl alcohol | 22.56 | 3.02 | 3.50 | 3.63 | 3.96 | 4.03 | 3.96 | 3.57 |
| 1-verbenone | 22.89 | 5.12 | 4.34 | 3.95 | 4.66 | 5.25 | 5.18 | 4.65 |
| borneol | 23.45 | 0.16 | 0.14 | -- | 0.14 | 0.19 | -- | -- |
| Nopol | 25.26 | 2.12 | 2.32 | 2.36 | 2.46 | 2.56 | 2.77 | 2.37 |
| Cis-carveol | 26.48 | 0.47 | 0.46 | 0.44 | 0.49 | 0.54 | 0.55 | 0.44 |
| Geraniol | 26.81 | 0.21 | 0.28 | 0.33 | 0.23 | 0.23 | 0.24 | 0.22 |
| p-cymen-8-ol | 26.99 | 0.15 | -- | -- | 0.14 | -- | -- | -- |
| Total identified compounds | | 99.86 | 99.99 | 100 | 100 | 99.97 | 100 | 100 |
| Monoterpene hydrocarbones | | 38.18 | 40.78 | 37.00 | 42.51 | 36.67 | 37.61 | 39.50 |
| Oxygenated monoterpenes | | 61.22 | 58.81 | 62.61 | 56.95 | 63.10 | 62.16 | 60.05 |
| Sesquiterpene hydrocarbos | | 0.46 | 0.40 | 0.39 | 0.54 | 0.20 | 0.23 | 0.45 |

T1 (100% Sand: 0 % loam), T2 (75% Sand: 25 % loam), T3 (66.75% Sand: 33.25 % loam), T4 (50% Sand: 50 % loam), T5 (33.25% Sand: 66.75 % loam), T6 (25% Sand: 75 % loam), and T7 (0% Sand: 100 % loam).

**Correlation Coefficient:**

Correlation coefficients of variables were presented in Tables (5 and 6). The values close to (1) indicates that the two variables are behaving almost identically. Conversely, the values close to (-1) indicate that the two variables are behaving in opposite manner. The values near to zero (0) indicate that the two variables are independent of each other. Data in Table (5) revealed that significant positive correlations were observed between all characters in the study with exception of no significant correlation during the 1$^{st}$ cut between essential oil content (%) and essential oil yield per plant. Oil yield had medium significant positive correlation with plant height (+0.88 for 1$^{st}$ cut and +0.93 for 2$^{nd}$ cut), branches number (+0.89 for 1$^{st}$ cut), herb fresh weight and oil percentage (+0.93) in the 2$^{nd}$ cut. Moreover, high significant positive correlation (+0.93) was produced between oil yield and oil percentage in the 2$^{nd}$ cut. The highest significant positive correlation (0.96-0.99) was observed between plant height and both fresh and dry weight of herb.

A few of the main essential oil constituents appeared to be highly inter-correlated (Table 6). Strong negative correlation (-0.86) was observed between camphene and camphor. Camphene ($C_{10}H_{16}$) is a crystalline bicyclic monoterpene hydrocarbon firstly isolated from the essential oil of AbiessibiricG in 1888. It is also obtained from alpha-pinene and in turn it can be converted into camphor through isobornyl acetate. Camphor ($C_{10}H_{16}O$), is a pleasant medicinal-smelling terpenoid, possesses antimicrobial, anesthetic, cough-suppressants properties. Camphor is produced from camphene through serious of action including intermolecular rearrangement, acetate capture, hydrolysis and oxidation (Nimitz, 1991; Comelli et al., 2004).

$$Camphene \xrightarrow[Hydrolysis]{\text{Wagner Meerwein rearrangement}} Isoborneol \xrightarrow{\text{Oxidation}} Camphor$$

The major essential oil constituents were camphor, α-pinene, eucalyptol, and camphene, respectively. Camphor showed negative correlations with both α-pinene and camhene (-0.724 and -0.857, respectively). Moreover, eucalyptol had a high significant negative correlation (-0.911) and high significant positive correlation (0.922) with monoterpene-hydrocarbons and oxygenated-monoterpenes, respectively. Eucalyptol ($C_{10}H_{18}O$) is an organic and colorless compound. Eucalyptol is a cyclic ether and monoterpenoid. It is also known by several synonyms such as 1,8-cineol, 1,8-cineole, cajeputol, 1,8-epoxy-p-menthane, 1,8-oxido-p-menthane, eucalyptol, eucalyptole, 1, 3, 3-trimethy l – 2 – oxabicyclo [2, 2,2] octane, cineol, and cineole. Eucalyptol is a substance in cough suppressant and mouthwash brands. It is inhibiting anti-inflammatory cytokine which in turn determines airway mucus hypersecretion and asthma. Eucalyptol is effective for nonpurulentrhinosinusitis, it is applied topically to reduce pain and inflammation, and it kills leukemia *in vitro*. Also camphene showed significantly negative correlation with monoterpene-hydrocarbons (-0.750) and significantly positive correlation with oxygenated-monoterpenes (0.725). Moreover, highly negative correlation (-0.999) was observed between monoterpene hydrocarbons and Oxygenated monoterpenes.

The results of this study suggested that soil type played an important role on plant growth, essential oil yield, as well as chemical compositions of essential oil.

**Table - 5: Correlation coefficients among different agro-morphological traits in Rosemarinus officinalis plant (upper values in each cell for 1st cut and lower values in each cell for 2nd cut)**

| Characters | Plant height | Branches Number | Herb fresh weight | Herb dry weight | Essential oil% | Essential oil yield |
|---|---|---|---|---|---|---|
| Plant height | --- | | | | | |
| Branches Number | 0.98*** <br> 0.76* | --- | | | | |
| Herb fresh weight | 0.96*** <br> 0.99*** | 0.89** <br> 0.76* | --- | | | |
| Herb dry weight | 0.96*** <br> 0.97*** | 0.93** <br> 0.84* | 0.94** <br> 0.97*** | --- | | |
| Essential oil% | 0.86* <br> 0.79* | 0.86* <br> 0.78* | 0.80* <br> 0.79* | 0.91** <br> 0.83* | --- | |
| Essential oil yield | 0.88** <br> 0.93** | 0.89** <br> 0.86* | 0.86* <br> 0.93** | 0.83* <br> 0.97*** | 0.65 <br> 0.93** | --- |

**Table - 6: Correlation coefficients among major chemical constituents in Rosemarinus officinalis plant essential oil**

| Characters | Comphore | α-pinene | eucalyptol | camphene | Monoterphene hydrpcarbones | Oxygenated monoterphpens | Sesquitepenes hydrocarbones |
|---|---|---|---|---|---|---|---|
| Comphore | --- | | | | | | |
| α-pinene | -0.724* | --- | | | | | |
| eucalyptol | -0.265 | -0.233 | --- | | | | |
| camphene | -0.857** | 0.574 | 0.633 | --- | | | |
| Monoterphene hydrpcarbones | 0.557 | 0.077 | -0.911** | -0.750* | --- | | |
| Oxygenated monoterphpens | 0.520 | -0.112 | 0.922** | 0.725* | -0.999*** | --- | |
| Sesquitepenes hydrocarbones | 0.091 | 0.403 | 0.781* | 0.323 | 0.735* | -0.767* | --- |

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