INFLUENCE OF WATER REGIME TREATMENTS ON GROWTH OF ROSMARINUS OFFICINALIS L. PLANT

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ABSTRACT: The current research was carried out at the Hort. Dept., Fac. of Agric., Benha Univ., Egypt, throughout the 2019/2020 and 2020/2021 seasons. To investigate the impact of water regime i.e. (100, 70 and 50% of field capacity) on growth of Rosmarinus officinalis L. plant in the two seasons. The results revealed that differences treatments of field capacity increased the growth parameters of rosemary plant in the two seasons. The use of field capacity at 100% achieved the highest values on all studied parameters of vegetative growth and some chemical composition, except the total carbohydrates % in both seasons. On contrary, the use of 50% FC scored the best values for total carbohydrates % and essential oil productivity in both seasons. Consequently, it is preferable to treat rosemary plants with FC at 100% in order to achieve the highest levels of vegetative growth parameters. On the other hand, it is possible to treat rosemary plant with 50% FC to obtain the highest essential oil productivity.

Key words: Rosmarinus officinalis, field capacity, vegetative growth, oil productivity.

INTRODUCTION

Rosmarinus officinalis L. is a Mediterranean evergreen plant that belongs to the Lamiaceae family. It is also of great importance due to the presence of essential oil, which has medical importance and is used in the perfume industry (Miguel et al., 2007). It is also characterized by many medicinal properties as it treats stomach pain and spasms and is considered an anthelmintic and has the advantage that its leaves are considered antioxidants in addition to its use in cooking purposes (Singh and Guleria, 2013). The volatile oil in rosemary has a percentage of 1.43 as mentioned by Zaouali et al. (2013). The main component of the volatile oil was 1.8-Cineole and its ratio reached to (35.8%). It has medical benefits as an antispasmodic, inflammatory and diabetic, in addition to its use as an antiseptic (Juhas et al., 2009; Abu-Al-Basal, 2010; Beninca et al., 2011). Water is one of the important factors that have an impact on plant growth and then on its productivity. At this time, it is better to use water resources efficiently due to the limited quantities of water, and it represents a challenge for researchers to find and provide water sources to work on increasing plant production, especially in tropical areas that are characterized by hot dry weather and in arid regions with limited water resources. However, Water has a great effect on the growth of plants. It was found that the rosemary plant, if exposed to water stress, growth parameters decreases. On contrary, the productivity of the volatile oil and its components may increase (Leithy et al., 2006). Also, as a result of water stress, the fresh, dry weights of the herb is completely and partially affected, in addition to the volatile oil and its components, and the total content of carbohydrates increases. On the contrary, the protein N, P and K % within the plant decreases (Khalid, 2006). In this
The content of chlorophyll is related to and affected by the lack of water, which shows that chlorophyll is related to the percentage of water in the leaves (Munne-Bosch and Alegre, 2000). Despite the studies that have been conducted and related to the different effects of irrigation on plant growth, it has been noted that they did not definitively explain the different effects of irrigation on the different growth stages of rosemary plants (Nicola’s et al., 2008). Therefore, this study was conducted to find out the effect of different water regimes (100, 70 and 50% field capacity) on the vegetative growth, chemical constituents and oil productivity of Rosmarinus officinalis L. plant.

**MATERIALS AND METHODS**

This study was carried out in the Experiment Farm of the Hort. Dept., Fac. of Agric., Benha University in 2019/2020 and 2020/2021 seasons.

**Plant materials:**

The uniform terminal cuttings of Rosmarinus officinalis L. were taken yearly from the mother plants which were kindly obtained from the Experimental Farm of the Moshtohor Faculty research in uniform size and length (25 cm) long with 10-12 pairs of leaves. The cuttings were planted in polyethylene bags in a mixture of clay:sand (1:1 v/v) on November 15th after that seedling were transplanted on March 21st in both seasons.

**Irrigation treatments:**

Plastic pots of 25 cm in diameter were used, perforated from the bottom, were packed with 3860 g of the soil, divided into three treatments (100%, 70% and 50% of field capacity). In 100% of field capacity, the amount of water added was 2316 ml, in 70% and 50% of field capacity the amount of water added were 1621 and 1158 ml, respectively.

All pots were irrigated with tap water at the previously assigned treatments. In the winter season, plants were irrigated once a week, while in the summer season, they were irrigated every 3 days. The number of irrigation times was calculated in a period of 6 months, 3 months in summer and 3 months in winter, as well as for a period of 12 months, 6 months in summer and 6 months in winter. The number of irrigation times in a 6-month period was 42, and the number of irrigation times in a 12-month period was 84.

**Chemicals fertilization:**

The recommended dose of chemical fertilizers as NPK was added in six equal doses, the first three doses were added during plant growth and until the first cut, and the other three doses were added after that and till the second cut. However, after planting a month, about 100 kg of ammonium sulfate/fed (1.56 g/pot) was added with repeated nitrogen fertilization monthly to obtain a good growing. Also, K fertilizer was added in batches of up to 25 kg per fed (0.39 g/pot) as potassium sulfate. Organic and phosphate fertilizers added 20 m³ decomposed organic fertilizer as well as 300 Kg of calcium super phosphate (3 g/pot), 100 Kg sulfur per fed (1 g/pot). Other agricultural practices were carried out during the growth of the rosemary plant when needed.

**Layout of the experimental:**

The experimental layout was simple factorial experience including 3 treatments. Each treatment was 3 replicated and each replicate consisted of 5 plants and the obtained data was subjected to statistical analysis according to Snedecor and Cochran (1989).

**Treatments:**

1. 100% field capacity.
2. 70% field capacity.
3. 50% field capacity.

**Data recorded:**

The plants were harvested twice / season (first and second cuts) on 15th July and 15th October in both seasons, by cutting the herb of the plants at 10 cm above the soil surface.
The following data were recorded in both seasons:

1. Vegetative growth
   - Plant height (cm).
   - Branches number/plant.
   - F.W. (g/plant).
   - D.W. (g/plant).

2. Chemical composition:
   In rosemary fresh leaves, chlorophylls (a & b) and carotenoides were estimated according to A.O.A.C. (1990). Also, in the dry leaves, N, P, K % and total carbohydrates were determined according to Horneck and Miller (1998), Sandell (1950), Horneck and Hanson (1998) and Herbert et al. (1971), respectively.

3. Essential oil production:
   The essential oil for each tasted treatment was extracted by hydro-distillation according to Guenther (1961).

RESULTS AND DISCUSSION

Vegetative growth:

1. Plant height (cm) and branches number/plant:
   It is clear from Table (1) that deficit irrigation treatments were significantly decreased the plant height and No. of branches of Rosmarinus officinalis plants. The tallest plants (30.27, 26.33, 27.00 and 18.33 cm, respectively) were achieved by applying 100% FC in both seasons, while the shortest plants (21.50, 19.67, 23.17 and 16.67 cm in the first and second cuts, respectively) were gained by using treatment of 50% FC at the first and second seasons, respectively. Also, the highest number of branches were recorded from 100% FC in two cuts in both seasons, compared with treatment of 50% FC as recorded the lowest values in both seasons, except the first cut of the first season the highest number of branches were recorded from 50% FC (15.67), compared to 100% FC treatment which gave (14.67) but the increment was insignificant. The results obtained are in line with Hassan et al. (2013) on Rosmarinus officinalis L., Mohamed et al. (2021) on Viola odorata and Karimzadeh et al. (2018) on Dracocephalum moldavica.

   These previous results indicate that the lack of water affects the fullness of the plant, which leads to reduced growth and slow development of cells, especially in the stem and leaves. Cell growth is greatly affected by water stress, and thus growth decreases, which is reflected in the effect on the decrease in plant height. From the above, it is clear that the deficit of water affected the rosemary plant, and this was evident in reducing its height and the growth of shoots (Nicola’s et al., 2008). The previous results are in agreement with Leithy et al. (2006), Bettaieb et al. (2009), Mohamed et al. (2021) and Ekren et al. (2012).

2. Fresh and dry weights (g/plant):
   Table (2) demonstrates that the fresh and dry weights of rosemary were significantly affected by using deficient irrigation treatments. It was observed that the fresh and dry weights/plant decreased with a decrease in the level of field capacity, and the lowest value was achieved by applying 50% FC treatment for both seasons.

   However, the highest values of fresh weight at 100% FC were (36.33, 87.17, 26.33 and 60.33 g, respectively), compared to the lowest values with 50% FC (30.83, 56.67, 20.08 and 50.83 g, respectively). Also, the dry weight gave the highest values at 100% FC (17.08, 35.59, 11.85 and 24.89 g, respectively), compared with 50%FC which gave minimum values (12.09, 20.57, 6.38 and 16.49 g, respectively) in both cuts of both seasons. These results are in agreement with those obtained by Bidgoli (2018) on Rosmarinus officinalis L. and Farsi et al. (2019) on Origanum majorana L.

   The reason for the results obtained to increase the plant’s yield of fresh herb is that the availability of irrigation leads to a high percentage of moisture around the roots, which follows the increase in the number of
roots and therefore the absorption of large quantities of nutrients, which is naturally reflected in the growth and production of a high vegetative biomass (Singh et al., 1997). It was also found that under water deficit, the dry weight decreases, which is a result of the decrease in chlorophyll content, as the previous results indicated, and thus the efficiency of photosynthesis decreases, as mentioned by Khalid (2006).

Chemical compositions:

1. N, P and K (%):

Table (3) declares that the decreasing of irrigation level from 100 to 50% FC was decreased N, P and K % in both cuttings of two seasons. In this respect, the highest values were recorded by applying 100% FC treatment, for N% were (2.103, 2.397, 2.197 and 2.250%, respectively), for P % were (0.234, 0.251, 0.246 and 0.279%, respectively) and for K % were (2.170, 2.327, 1.967 and 2.197%, respectively). However, the lowest values of N, P and K %, achieved by the lowest irrigation level (50% FC), for N % recorded (1.357, 1.590, 1.577 and 1.867%, respectively), for P % recorded (0.132, 0.162, 0.152 and 0.200%, respectively) and K% recorded (1.720, 1.673, 1.413 and 1.677%, respectively). These results are in line with Hassan et al. (2013) and El-Leithy et al. (2018).

It is clear that the previous results affected by deficient irrigation, the negative
impact of which was reflected on the total nitrogen, phosphorous and potassium content of rosemary plant, resulted from the decrease in vegetative growth due to the decrease of absorption nutrients (Pascale et al., 2001). These results obtained in our study on the low of irrigation and its association with decreased growth due to the low content of nutrients, and it was found that high irrigation level could compensate for nutrient deficiency and agree with Silber et al. (2003).

2. Total carbohydrates (%):

It is obvious from Table (4) that the highest percentage of total carbohydrates was significantly increased by deficit irrigation and was recorded at (50% FC) treatment in two cuttings in both seasons. However, at 100% FC recorded the lowest values which were (12.373, 16.457, 15.09 and 17.61%, respectively), compared with 50% FC treatment which recorded the highest values (21.947, 23.633, 19.85 and 24.77%, respectively) in two cuttings in both seasons.

The aforementioned results are in conformity with those reported by Mohammadzadeh and Pirzad (2020) on (Lavandula officinalis L.), rosemary (Rosmarinus officinalis L.) and thyme (Thymus vulgaris L.).

Table 3. Effect of different irrigation treatments on N, P and K% of Rosmarinus officinalis L. plant during 2019/2020 and 2020/2021 seasons.

| Treatments | N (%) | P (%) | K (%) |
|------------|-------|-------|-------|
|            | 1st cut | 2nd cut | 1st cut | 2nd cut | 1st cut | 2nd cut |
| 100% F.C.  | 2.103  | 2.397  | 0.234  | 0.251  | 2.170  | 2.327  |
| 70% F.C.   | 1.660  | 1.770  | 0.207  | 0.228  | 2.047  | 2.190  |
| 50% F.C.   | 1.357  | 1.590  | 0.132  | 0.162  | 1.720  | 1.673  |
| L.S.D at 0.05 | 0.16  | 0.27  | 0.072  | 0.002  | 0.12  | 0.61  |

Table 4. Effect of different irrigation treatments on total carbohydrates (%) of Rosmarinus officinalis L. plant during 2019/2020 and 2020/2021 seasons.

| Treatments | 1st cut | 2nd cut |
|------------|---------|---------|
| 100% F.C.  | 12.373  | 16.457  |
| 70% F.C.   | 18.790  | 20.483  |
| 50% F.C.   | 21.947  | 23.633  |
| L.S.D at 0.05 | 3.94  | 3.43  |

3. Chlorophylls a and b:

Table (5) indicates that chlorophylls a and b contents of rosemary significantly decreased by using irrigation level from 100 to 50% FC. The highest values in this respect (0.808, 0.893, 0.751 and 0.963 mg g^-1 F.W., respectively) for chlorophyll a and (0.565, 0.760, 0.580 and 0.791 mg g^-1 FW, respectively) were recorded for chlorophyll b at the highest irrigation level (100% FC) in both cuts in two seasons in the same table, respectively.
Table 5. Effect of different irrigation treatments on chlorophyll a and b (mg/g F.W.) of *Rosmarinus officinalis* L. plant during 2019/2020 and 2020/2021 seasons.

| Treatments | Chlorophyll a (mg/g F.W.) | Chlorophyll b (mg/g F.W.) |
|------------|--------------------------|--------------------------|
|            | 1st cut | 2nd cut | 1st cut | 2nd cut |
| 1st season |         |         |         |         |
| 100% F.C.  | 0.808   | 0.893   | 0.565   | 0.760   |
| 70% F.C.   | 0.785   | 0.815   | 0.539   | 0.712   |
| 50% F.C.   | 0.730   | 0.766   | 0.513   | 0.657   |
| L.S.D at 0.05 | 0.072 | 0.10   | 0.002   | 0.14    |
| 2nd season |         |         |         |         |
| 100% F.C.  | 0.751   | 0.963   | 0.580   | 0.791   |
| 70% F.C.   | 0.648   | 0.778   | 0.538   | 0.699   |
| 50% F.C.   | 0.592   | 0.723   | 0.470   | 0.608   |
| L.S.D at 0.05 | 0.16  | 0.12    | 0.14    | 0.14    |

**Oil productivity:**

1. **Essential oil percentage:**

   Table (6) reveals that volatile oil percentage was increased by deficit irrigation level was obtained by irrigation the treatment of rosemary plant at 50% FC was scored the highest percentage (0.147, 0.213, 0.167 and 0.223%, respectively) in two cuttings in both seasons. However, the treatment of 100% FC achieved the lowest values (0.103, 0.163, 0.107 and 0.127% in both cuts, in two seasons, respectively) in this concern. These results are in line with by Bidgoli (2018) and Raffo *et al.* (2020) on rosemary plant.

   The possible reason for these results is that due to the low of water, the density of the oil glands increases due to the lack of leaf area, which follows the accumulation of large quantities of volatile oil (Simon *et al*., 1992). In this context, Khalid (2006) and Ekren *et al.* (2012) they stated that the different water treatments affected of oil productivity.

2. **Essential oil compositions:**

   Data presented in Table (7) and Figs. (1-3) indicate that the irrigation levels improved volatile oil compositions of rosemary plant. The volatile oil constituents of rosemary included 11 compounds were identified, i.e. (α-pinene, Camphene, β-pinene, limonene, 1,8 cineol, camphor, α-terpineol, borneol, bornyl acetate, Eugenol and β-caryophyllene).

   However, the main component was 1,8 cineole ranged from (15.15 to 15.78%), followed by α-pinene ranged from (9.91 to 10.10%).

Table 6. Effect of different irrigation treatments on Essential oil percentage of *Rosmarinus officinalis* L. plant during 2019/2020 and 2020/2021 seasons.

| Treatments | 1st cut | 2nd cut |
|------------|---------|---------|
|            |         |         |
| 1st season |         |         |
| 100% F.C.  | 0.103   | 0.163   |
| 70% F.C.   | 0.110   | 0.190   |
| 50% F.C.   | 0.147   | 0.213   |
| L.S.D at 0.05 % | 0.072 | 0.072   |
| 2nd season |         |         |
| 100% F.C.  | 0.107   | 0.127   |
| 70% F.C.   | 0.130   | 0.187   |
| 50% F.C.   | 0.167   | 0.223   |
| L.S.D at 0.05 % | 0.002 | 0.002   |
Table 7. GLC analysis of the essential oil of rosemary plants in the second cut of the second season (2020/2021).

| Peak No. | Components       | Area %       |
|----------|-----------------|--------------|
|          |                 | F.C. at 100% | F.C. at 70% | F.C. at 50% |
| 1        | α-pinene        | 9.91         | 11.58       | 14.87       |
| 2        | Camphene        | 5.59         | 6.30        | 7.61        |
| 3        | β-pinene        | 3.28         | 3.85        | 4.95        |
| 4        | Limonene        | 3.76         | 4.39        | 5.83        |
| 5        | 1,8 cineole     | 15.15        | 15.76       | 15.78       |
| 6        | Camphor         | 13.99        | 12.79       | 12.07       |
| 7        | α-terpineol     | 2.05         | 1.99        | 1.97        |
| 8        | Borneol         | 3.61         | 3.59        | 5.52        |
| 9        | Bornyl acetate  | 9.41         | 10.04       | 5.92        |
| 10       | Eugenol         | 5.83         | 5.74        | 3.81        |
| 11       | β-caryophyllene | 1.52         | 1.25        | 1.98        |
| Unknown  |                 | 25.9         | 22.72       | 19.69       |
| Total    |                 | 100.00       | 100.00      | 100.00      |

Fig. 1. Effect of irrigation treatment at (100% F.C.) on essential oil compositions in the second cut of the second season.

Fig. 2. Effect of irrigation treatment at (70% F.C.) on essential oil compositions in the second cut of the second season.
14.87%) from treatment 100% FC to 50% FC, respectively. In addition to unknown components with values from (25.9% at 100% FC to 19.69% at 50% FC).

In general, it is clear from the previous results that the field capacity at (100% FC) was better in the case of vegetative growth parameters and total N, P and K %, while the field capacity at (50% FC) achieved the best value for total carbohydrates % and oil productivity, followed by field capacity at (70% FC).

Abstractly, this gives us an explanation that the oil productivity, the final product was not affected by the increase in the field capacity at (100%FC) and this is a good economic indication for this study.

REFERENCES
Abu-Al-Basal, M.A. (2010). Healing potential of *Rosmarinus officinalis* L. on full thickness excision cutaneous wounds in alloxan-induced-diabetic BALB/c mice. J. Ethnopharmacol., 131: 443–450.
A.O.A.C. (1990). Official methods of analysis (15th ed.). Association of official Analytical Chemists, Washington D.C., USA., 1298 p.
Beninca, J.P.; Dalmarco, J.B.; Pizzolatti, M.G. and Frode, T.S. (2011). Analysis of the anti-inflammatory properties of *Rosmarinus officinalis* L. in mice. Food Chem., vol. 124, pp. 468–475.
Bettaieb, I.; Zakhama, N.; Aidiwannes, W.; Khouk, M.E. and Marzouk, B. (2009). Water deficit effects on *Salvia officinalis* fatty acids and essential oils composition. Scientia Horticulturae, 120: 271–275.
Bidgoli, R.D. (2018). Effect of drought stress on some morphological characteristics, quantity and quality of essential oil in Rosemary (*Rosmarinus officinalis* L.). Advancement in Medicinal Plant Research, 6(3):40-45.
Ekren, S.; Sonmez, C.; Ozacakal, E.; Kurttas, Y.S.K.; Bayram, E. and Gurgulu, H. (2012). The effect of different irrigation water levels on yield and quality characteristics of purple basil (*Ocimum basilicum* L.). Agricultural Water Management, 109:155-161.
El-Leithy, A.S.; Hanafy, M.S. and Anaam, G.A.M. (2018). Effect of irrigation intervals, Cyto flow Amin-50 and their interaction on rosemary (*Rosmarinus officinalis* L.), II- On chemical constituents. Middle East Journal of Agriculture Research, 7(3):768-781.
Farsi, M.; Abdollahi, F.; Salehi, A. and Ghasemi, S. (2019). Growth responses of *Origanum majorana* L. to methyl jasmonic acid under limited irrigation conditions. Journal of Essential Oil Bearing Plants, 22(2):455-468.
Guenther, E. (1961). The Essential Oil, 4th Ed., vol. III.D. Van. Nostrand company, Inc., New York.

Hassan, F.A.S.; Bazaid, S. and Ali, E.F. (2013). Effect of deficit irrigation on growth, yield and volatile oil content on Rosmarinus officinalis L. Plant. Journal of Medicinal Plants Studies, 1(3):12-21.

Herbert, D.P.; Phipps, J. and Strange, R.E. (1971). Determination of total carbohydrates, Methods in Microbiology, 5(8):290-344.

Horneck, D.A. and Hanson, D. (1998). Determination of potassium and sodium by flame emission spectrophotometry. In: Kolra, Y.P. (ed.), Handbook of Reference Methods for Plant Analysis, Taylor and Francis Group, LLC., USA, pp. 153-155.

Horneck D.A. and Miller R.O. (1998). Determination of total nitrogen in plant tissue. In: Kolra, Y.P. (ed.), Handbook of Reference Methods for Plant Analysis, Taylor and Francis Group, LLC., USA, pp. 75-83.

Juhas, S.; Bukovska, A.; Ciko’s, S.; Czikkova, S.; Fabian, D. and Koppel, J. (2009). Anti-inflammatory effects of Rosmarinus officinalis essential oil in mice. Acta Vet. Brno, 78:121–127.

Karimzadeh, A. K.; Ghorbanpour, M.; Marefatzadeh, K. M. and Hatami, M. (2018). Influence of drought stress, biofertilizers and zeolite on morphological traits and essential oil constituents in Dracocephalum moldavica L. Journal of Medicinal Plants, 17(67):91-111.

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

Leithy, S.; El-Meseiry, T.A. and Abdallah, E.F. (2006). Effect of biofertilizer, cell stabilizer and irrigation regime on rosemary herbage oil yield and quality. Journal of Applied Sciences Research, 2(10):773-779.

Miguel, M.G.; Guerrero, C.; Rodrigues, H. and Brito, J. (2007). Essential oils of Rosmarinus officinalis L., effect of harvesting dates, growing media and fertilizers. Proceedings of the 3rd IASME/WSEAS International Conference on Energy, Environment, Ecosystems and Sustainable Development, Agios Nikolaos, Greece, pp. 24–26.

Mohammadzadeh, S. and Pirzad, A. (2020). Biochemical responses of mycorrhizal inoculated lamiaceae (lavender, rosemary and thyme) plants to drought: a field study. Soil Science and Plant Nutrition, 67(1):41-49

Mohamed, S.M.; Abou El-Ghaiet, E.M.; Ghatas, Y.A.A.; Hammam, K. and Shahin, A. (2021). Effect of proline, methyl salicylate, and magnetic field in the salinity of vegetative, flowering growth, chemical composition and oil content on Viola odorata, Linn. Proceeding of The 5th International Conference on Biotechnology Applications in Agriculture (ICBAA), Benha University, 8 April 2021, Egypt (Conference Online)., pp. 573-581.

Mohamed, S.M.; Ghatas, Y.A.A.; Sami, S.S. and Naguib, A.M. (2021). Effect of different types of cutting and planting of Conocarpus lancifolius. Future J. Hort., 3:1-6.

Munne-Bosch, S. and Alegre, L. (2000). Changes in carotenoids, tocopherols and diterpenes during drought and recovery, and the biological significance of chlorophyll loss in Rosmarinus officinalis plants. Planta , 210:925-931.

Nicola's E., Ferrandez, T.; Rubio, J.S.; Alarco'n, J.J. and Sa'ñchez-Blanco, M. (2008). Annual water status, development, and flowering patterns for Rosmarinus officinalis plants under different irrigation conditions. Hortscience, 43(5):1580–1585.

Pascale, S.D.; Paradiso, R. and Barbieri, G. (2001). Recovery of physiological parameters in Gladiolus under water stress. Colture Protette, 30(7):65-69.

Raffo, A.; Mozzanini, E.; Nicoli, S. F.; Lupotto, E. and Cervelli, C. (2020). Effect of light intensity and water
availability on plant growth, essential oil production and composition in *Rosmarinus officinalis* L. European Food Research and Technology, 246:167–177.

Sandell, E.B. (1950). Colorimetric determination of traces of metals, 2nd Ed. Interscience. Pub. Inc. New York, USA, 673 p.

Silber, A.; Xu, G. and Wallach, R. (2003). High irrigation frequency: the effect on plant growth and on uptake of water and nutrients. *Acta Hort.* (ISHS), vol. 627, pp. 89-96.

Simon, J.E.; Reiss-Buhnenheinra, D.; Joly, R.J and Charles, D.J. (1992). Water stress induced alterations in essential oil content and composition of sweet basil. *J. Essent. Oil Res.*, 4:71–75.

Singh, M. and Guleria, N. (2013). Influence of harvesting stage and inorganic and organic fertilizers on yield and oil composition of rosemary (*Rosmarinus officinalis* L.) in a semi-arid tropical climate. *Industrial Crops and Products*, 42:37-40.

Singh, M.; Rao, R.S.G. and Ramesh, S. (1997). Irrigation and nitrogen requirement of lemongrass (*Cymbopogon flexuosus* (Sleud) Wats) on a red sandy loam soil under semi-arid tropical conditions. *J. Essential Oil Res.*, 9(5):569-574.

Snedecor, G.W. and Cochran, W.G. (1989). Statistical methods. 8th Ed., The Iowa State Univ. Press, Iowa, U.S.A., 503 p.

Zaouali, Y.; Hnia, C.; Rim, T. and Mohamed, B. (2013). Changes in essential oil composition and phenolic fraction in *Rosmarinus officinalis* L. var. typicus Batt. organs during growth and incidence on the antioxidant activity. *Industrial Crops and Products*, 43:412-419.