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Effects Of Macronutrient Fertilization On Plant Growth, Essential Oil Content, And Chemical Composition In Medicinal And Aromatic Plants Grown Under Different Environmental Conditions: A Review

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Abstract

The rates of macro-elements in the soil under different environmental conditions is one of the most investigated aspects of medicinal plants research worldwide. In cultivating vegetative crops, applying high rates of macronutrient fertilization increased plant growth and vegetative yield, but when the cultivation goal was growing medicinal and aromatic plant for large quantities of high-quality essential oils, the outcomes of macronutrient fertilization may vary dramatically. Macronutrient fertilization has been applied and its influence studied in detail for many medicinal and aromatic plants grown under different environmental systems. Based on the results of previous studies, it can be concluded that applying adequate levels of macronutrient fertilization, foliar and split applications, increases essential oil content and components for several medicinal and aromatic plants. The present review also revealed that it helps medicinal and aromatic producers increase the yield of essential oil and other secondary metabolites used in different commercial and industrial productions. Moreover, this review also presents important information for reducing environmental pollution, which is particularly important in developed and developing countries.

Keywords: Medicinal herb, aromatic herb, foliar application, macronutrient, essential oil

Introduction

Medicinal plants have been utilized to control different human diseases from over 60,000 years ago. Based on studies of the pollen grains of eight medicinal plants found in graves in the Middle East, Neanderthal man valued these eight herbs as medicinal agents in treating different human diseases (Boroomand & Grouh, 2012). Different medicinal and aromatic plants are cultivated for their secondary metabolites, including essential oils, phenolics, alkaloids, saponins, terpenes, lipids, and carbohydrates. The secondary metabolites produced by different plants are utilized by different pharmaceutical and cosmetical industries in both developed and developing countries. Therefore, the plants that produce these secondary metabolites are defined as medicinal and aromatic plants (Lubbe & Verpoorte, 2011). Ornamental plants and field crops also produce essential oils and other secondary metabolites, but these chemical materials are used in the food industry. Many growers are interested in using smart fertilization, modern irrigation and cultivation methods, and modern cultivars to increase the essential oils and secondary metabolites of medicinal plants (Nurzyńska-Wierdak, 2013).

Several abiotic and biotic stresses influence the production of essential oils and secondary metabolites from different medicinal and aromatic plants. These stresses include temperature, humidity, light incidence, drought, soil salinity, heavy metals, and nutrient availability (Li et al., 2020). Nutrition deficiency is one of the most influential abiotic factors on secondary metabolites and phytochemicals in medicinal and aromatic plants grown under different environmental conditions. Plant nutrition factors play key roles in the growth and development of different medicinal plants. The biochemical pathways of secondary metabolites synthesis, including essential oils, can be increased when the medicinal plants are treated with an efficient rate of plant nutrients (Zheljazkov et al., 2010; Alhasan et al., 2020; Alhasan et al., 2021). Thus, macro- and micronutrients are major factors affecting plant growth and the production of secondary metabolites of medicinal plants when applied in inadequate levels to medicinal plants. Therefore, the maximum rates of secondary metabolites can be obtained if plant nutrients are applied at optimum levels (Nagaveni et al., 2018).

Plant macronutrients comprise six elements classified into two groups, i.e. primary and secondary macro-elements. Nitrogen (N), phosphorus (P), and potassium (K) belong to the first group, while the sulfur (S), calcium (Ca), and magnesium (Mg) elements belong to the secondary macronutrient group (Boroomand and Grouh, 2012). Nitrogen is one of the primary macronutrients required in large amounts by medicinal plants. It provides medicinal plants with energy for growing and developing by building different organic compounds, including chlorophyll, amino acids, proteins, enzymes, and nucleic acids. Under conditions of N deficiency, the essential oils of plants can be reduced. Thus, applying adequate rates of nitrogen fertilizer can increase essential oil production (Alhasan et al., 2020; Sharma et al., 2020; Nurzyńska-Wierdak, 2013). Phosphorus is another important primary macronutrient for the development of plant growth in cultivated medicinal plants. It plays a significant role in cell division, flower initiation, maturing of fruit and seed, essential oil content, and other secondary metabolites (Boroomand & Grouh, 2012; Sonmez, 2018). Potassium is another macronutrient required in large amounts by different medicinal and aromatic plants. In addition to the above-mentioned primary macro-elements, secondary macronutrients (calcium, sulfur, and magnesium) should also be noted for their roles in the development of essential oil-producing plants and the biosynthesis of essential oils (Nagaveni et al., 2018; Nurzyńska-Wierdak, 2013). Sulfur, for example, is essential for better growth and biosynthesis of protein and chlorophyll in medicinal plants (Chowdhury et al., 2020). Under conditions of magnesium deficiency, the concentration of chlorophyll in medicinal plant tissue can be reduced, because magnesium is located in the center of the chlorophyll of the plant. Moreover, magnesium activates more than 200 enzymes (e.g., ATPase, phosphatase, RNA polymerases, carboxylase, protein kinase, and glutathione synthase) and is also essential for the metabolism of vitamin C, calcium, phosphorus, and potassium. It is also involved in the transport of ions, regulation, and cation balance in different medicinal and aromatic plants (Kiapour et al., 2020).

The present review focuses on the effects of applying macronutrients on plant growth, essential oil content, and secondary metabolites of different medicinal and aromatic plants grown under different environmental conditions. It also intends to demonstrate the great impact such application has on the cultivation and production of medicinal plants.

Influence of nitrogen on plant growth and essential oil of medicinal and aromatic plants

Nitrogen is one of the most important macronutrients that aids plant growth and development. Nitrogen availability in soil fluctuates in both place and time because of environmental factors, including soil temperature, precipitation, wind, and soil type and pH. Thus, the nitrogen form preferred in plants depends on plant adaptation to soil conditions. For example, plants grown under acidic soil conditions tend to absorb ammonium, while plants grown under aerobic soil conditions tend to take up nitrate (Masclaux-Daubresse et al., 2010). Under agricultural conditions, different forms of nitrogen are available to plants, but nitrate NO_3^- and ammonium NH_4^+ are two major inorganic nitrogen forms preferred for most plants grown under different environmental systems (Wirèn et al., 1997). Nitrate assimilation is less energetically efficient than that of ammonium, because ammonium can be directly incorporated into glutamate, while nitrate should be reduced to ammonium before being assimilated. Moreover, ammonium is only assimilated into amino acids in the root tissues to avoid toxic accumulation, whereas nitrate can be incorporated into different organic compounds in both root and leaf tissues (Wang & Macko, 2011).

Essential oils and other secondary metabolites are significantly influenced by several factors, which also influence nitrogen uptake and are used by different medicinal and aromatic plants. These factors can be nitrogen rate or form, time of application, and method of N application (Nurzyńska-Wierdak, 2013; Wirèn et al., 1997). In case of N form, greenhouse studies have evaluated the effects of nitrogen form on the essential oil content of thyme (Thymus vulgaris L.). The results showed that applying ammonium nitrate fertilizer can increase different plant parameters, including plant height, total number of branches, and essential oil content of thyme (Basal et al., 2019). Ahmadi et al. (2020) reported that the maximum values of plant growth parameters, total phenolic, total flavonoids, and essential oil content were obtained in Echinacea purpurea L. grown under greenhouse conditions when plants were treated with novel nitrogen slow-release fertilizer rather than urea fertilizer. These authors reported that applying N slow-release fertilizers can also improve and increase different phytochemical properties of the plant, because these types of N fertilizers have a polymeric structure. Lemon balm (Melissa officinalis L.) has been treated with different forms of nitrogen fertilizer (urea, sulfur-coated urea, and neem-coated urea) under field conditions. Those plants treated with sulfur-coated urea produced the maximum values of N uptake, nitrogen agronomy efficiency, and nitrogen physiological efficiency compared with other treatments (Aziz & El-Ashry, 2009).

In the case of medicinal and aromatic plants that synthesize essential oils, applying optimum rates of nitrogen fertilizer can effectively increase essential oil content. Ali et al. (2021) reported that applying urea at a rate of 120 kg N ha^{-1} is recommended to achieve maximum calyx yield of roselle (Hibiscus sabdariffa L.) grown under field conditions. Urea applied to coriander at a rate of 150 kg N ha^{-1} to (Coriandrum sativum L.) grown under field conditions showed the highest values of plant height, shoot dry weight, total number of umbels, seed yield, and essential oil yield (Abdollahi et al., 2016). Urea as a nitrogen fertilizer influences different agronomic traits and the essential oil yield of basil (Ocimum basilicum L.), and applying 60 kg N ha^{-1} resulted in a significant increase in the essential oil yield compared to other treatments (Alhasan et al., 2020). However, applying high rates of N fertilizer to different basil cultivars decreased total phenolic contents, rosmarinic acid levels, and caffeic acid concentration compared to plants grown under limited nitrogen growing conditions (Nguyen & Niemeyer, 2008). These authors also found significant differences in polyphenolic content and antioxidant activity between basil cultivars.

Under different environmental systems, the foliar application of nitrogen fertilizer is another factor that influences the nitrogen uptake by different medicinal and aromatic plants. Different sources of N fertilizer can be used to feed plants, but the urea form of N fertilizer is most commonly applied in foliar applications (Nurzyńska-Wierdak, 2013). Compared to the soil N application method, the foliar application of nitrogen in urea form increased vegetative growth, essential oil content, and chemical compositions in thyme (Jabbari et al., 2011). In another case, the leaf dry weight of Stevia rebaudiana grown under high poly-tunnel conditions was higher in plants treated with the foliar application of KNO_3 compared to other application methods (Mahajan et al., 2020). In the case of French tarragon (Artemisia dracunculus L.) cultivated under field conditions, maximum values of plant height, leaf area, total number of branches, leaf dry weight, leaf K and Ca contents, essential oil %, and oil yield were obtained in plants treated with foliar KNO_3 application (Heidari et al., 2014). Nurzyńska-Wierdak, (2012) reported that foliar application of urea contributes to increased linalool and epi-α-cadinol concentrations as well as decreased geraniol, eugenol, and 1,8-cineole contents in the essential oil of basil plants grown under high polyethylene (PE) foil tunnel conditions. However, basil plants treated with foliar ammonium nitrate have given higher essential oil yields and yield components compared to other application methods (Nurzyńska-Wierdak et al., 2013).

The production of secondary metabolites in medicinal and aromatic plants can be increased when nitrogen use efficiency (NUE) is increased in these plants. In medicinal and aromatic plants, the definition of NUE differs depending on whether plants are grown to produce biomass, grain yield, or essential oil content. However, NUE for most medicinal and aromatic plants depends on how plants extract different forms of nitrogen fertilizer applied through soil or foliar application methods, assimilate these N forms (NO_3^- and NH_4^+), and remobilize organic N compounds into the plant Masclaux-Daubresse et al., 2010). Under field conditions, applying urea fertilizer on common sage (Salvia officinalis L.) plants has resulted in higher biomass yields and essential oil contents. However, the control treatment (unfertilized treatment) showed the highest value of NUE of all fertilized treatments (Karimi et al., 2021). In general, using adequate levels of nitrogen fertilizer can increase plant growth, essential oil, seed yield, and also NUE in cases of medicinal and aromatic plant production. Under field conditions, the white cultivar of roselle treated with 60 N kg/ha showed the highest values of different plant parameters and the dry weight of calyces compared to other treatments. Based on biomass yield, applying 60 kg N/ha resulted in a higher NUE value compared with the application of 120 kg N ha^{-1} (Ali et al., 2021). Under greenhouse conditions, Hypericum pruinatum plants were treated with five rates of nitrogen fertilizer (0, 30, 60, 90, and 120 kg N/ha), and applying 60-90 kg N/ha increased herb yield, NUE, secondary metabolites, and antioxidant activities compared to using 120 kg N ha^{-1} (Radušienė et al., 2019). Four rates of nitrogen fertilizer (0, 40, 80, and 120 kg N/ha) were applied to Greek oregano (Origanum vulgare L.) plants grown under field conditions, and the 80 kg N/ha treatment resulted in the highest herbage yield, NUE, and essential oil components compared to the 120 kg N/ha treatment (Karamanos & Sotiropoulou, 2013). However, Greek oregano plants grown under field conditions were treated with three rates of nitrogen fertilizer (0, 150, and 300 kg N/ha), and treatment with the highest rate of N fertilizer (300 kg n/ha) gave maximum values of leaf dry yield and essential oil content (Giannoulis et al., 2020).

Increasing the rates of nitrogen fertilizer significantly contributed to an increase in essential oil yield in basil (Alhasan et al., 2020), peppermint (Zheljazkov et al., 2010), and chamomile (Hadi et al., 2015). Zheljazkov et al. (2008) stated that the highest essential oil yield can be obtained in basil by applying 50-60 kg N ha^{-1}. Moreover, nitrogen application modifies the percentage of linalool, eucalyptol, eugenol, and bornyl acetate in the essential oil of basil. Under greenhouse conditions, American skullcap (Scutellaria lateriflora) plants were treated with six rates of nitrogen fertilizer (0, 50, 100, 200, 400, and 800 kg N ha^{-1}) and ammonium nitrate applied as a source of inorganic N fertilizer. Applying the adequate N rate (400 kg N ha^{-1}) resulted in maximum values of aboveground dry matter (ADM), baicalein concentration, baicalein yield, and chrysin yield. However, applying different rates of N fertilizer did not increase scutellarin concentration or yield (Shiwakoti et al., 2016). Chinese herb (Astragalus mongolica) grown under field conditions was treated with six rates of nitrogen fertilizer (0, 37.5, 75, 112.5, 150, and 187.5 kg N ha^{-1}), and urea was utilized as the nitrogen fertilizer. Applying an adequate rate of N fertilizer (112.5 kg N/ha) significantly increased the root traits, biomass yield, and active compounds, including ononin, calycosin, and formononetin (Wang et al., 2020).

Considering the results of previous studies, it can be concluded that nitrogen fertilizer increases vegetative growth, essential oil content, and the production of secondary metabolites in different medicinal and aromatic plants grown under different environmental conditions. Several human and environmental issues can arise when farmers apply high rates of N fertilizer. Moreover, nitrogen use efficiency (NUE) can be reduced. Thus, using an adequate level of nitrogen fertilizer is required for the production of medicinal and aromatic plants. Moreover, changes in the secondary metabolites contents must be considered as more important than increases in biomass or grain yield under different application methods of N, different sources of N fertilizer, and different rates of N fertilizer.

Effect of phosphorus fertilizer on vegetative growth, essential oil content, and secondary metabolites of different medicinal and aromatic plants

Following nitrogen, phosphorous is one of the most important macro-elements required in large amount by medicinal and aromatic plants to grow well, produce enough root size, and reproduce different secondary metabolisms (Noh et al., 2017). Under different environmental conditions, phosphorus plays a significant role in root development, cell division, flowering initiation, as well as fruit maturing for different medicinal plants (Sonmez, 2018; Khalid, 2012). The secondary metabolites of medicinal and aromatic plants can also be increased by treating these plants with phosphorus fertilizers (Khalid, 2014). Moreover, different plant pathogens influencing medicinal plants can be reduced by applying phosphorus fertilizers (Khalid, 2012).

Using the optimum rate of phosphorus fertilizer increases vegetative growth, essential oil content, and different secondary metabolites of medicinal and aromatic plants. Under field conditions, phosphorus fertilizer applied at 200-250 kg ha^{-1} increased different leaf parameters, essential oil content, and thymol yield (Saffari et al., 2013). However, six rates of phosphorus fertilizer (0, 50, 100, 150, 200, and 250 kg ha^{-1}) were applied on thyme grown under field conditions, and the application of 150 kg/ha increased biomass yield and essential oil content; however, increasing the rate of phosphorus fertilizer did not increase the secondary metabolites, including thymol (Omidbaigi & Arjmandi, 2002). Under field conditions, different rates of phosphorus fertilizer (0, 20, and 40 kg ha-1) were applied to black cumin (Nigella sativa L.) plants, and the 20 kg/ha treatment achieved the maximum values of seed yield and yield components compared with other treatments (Tuncturk et al., 2011). Five different rates of phosphorous fertilizer (0, 15, 30, 45, and 60 kg/ha) were applied on snake tomato (Trichosanthes cucumerina L.), and statistical analysis showed that 30 kg P_2O_5 ha^{-1} gave statistically higher values for different plant parameters, yield, and yield components compared to other phosphorus treatments (Idowu et al., 2013). Under field conditions, black cumin plants were treated with three levels of phosphorus fertilizer (0, 40, and 80 kg ha^{-1}), and applying the adequate level of phosphorus (40 kg/ha) resulted in the highest values of plant height, total number of capsules, and grain yield (Shirmohammadi et al., 2014). Under greenhouse conditions, peppermint (Mentha piperita L.) plants treated with 40 mg P_2O_5 kg^{-1} produced the highest essential oil yield (45% increasing) compared to those treated with 10 mg P_2O_5 kg^{-1} (Arango et al., 2012). In the case of lavender (Lavandula angustifolia Mill) plants grown under greenhouse conditions, the application of phosphorous fertilizer in an adequate level (50-60 mg/L) increased different vegetative plant parameters and improved essential content. The application of 60 mg/L phosphorous showed the maximum values of 1,8-cineole, camphor, α-terpineol, borneol, and myrtenol in the essential oil of lavender (Chrysargyris et al., 2016). On the other hand, three rates of phosphorus fertilizer (0, 20, and 40 kg/ha) were applied to black cumin grown under field conditions, and the highest rate of phosphorus (40 kg/ha) resulted in maximum values of different vegetative parameters, seed yield, and yield components. However, applying different rates of phosphorus fertilizer did not significantly increase the seed size of black cumin (Yimam et al., 2015). Four different levels of phosphorus fertilizer (0, 12, 24, and 36 kg/ha) were applied to parsley (Petroselinum crispum L.), and statistical analysis showed that the high rate of phosphorus gave statistically higher values for different plant traits, including the essential oil yield, β-myrcene, 1,3,8-p-menthatriene, myristcin, and β-phellandrene content in oil of parsley (Alharbi et al., 2019). Under field conditions, four rates of phosphorus fertilizer (0, 50, 100, and 150 kg/ha) were applied at planting time to feverfew (Tanacetum parthenium L.) plants, and the treatment of 150 kg/ha produced maximum values of essential oil content, camphor, and chrysanthenyl-acetate (Saharkhiz et al., 2007). Applying three rates of phosphorus fertilizer (0, 0.8, and 1.6 g pot^{-1} as super phosphate fertilizer) on dragonhead (Dracocephalum moldavica L.) grown under greenhouse conditions and using a high rate of phosphorus fertilizer (1.6 g/pot) increased the fresh weight of herb, essential oil content, and oil yield compared to other treatments (Said-Al Ahl & Abdou, 2009). However, applying high rates of phosphorous fertilizer also reduced essential oil yield in some medicinal and aromatic plants and influence the environment (Emongor et al., 1990).

Influence of potassium fertilizer on plant growth and secondary metabolisms production of various medicinal and aromatic plants

Potassium is another macro-element that is required by different medicinal and aromatic plants grown under different environmental conditions for increasing plant growth and improving the production of secondary metabolites. Potassium is transferred into plants through high and low affinity K^+ transporter systems, and it is found in high levels in phloem and meristem tissues in medicinal and aromatic plants (Chrysargyris et al., 2017). In medicinal and aromatic plants, potassium induces several responses, including at morpho-physiological and molecular levels. This nutrient also acts as a cofactor enzyme, which includes enzymes that relate to the synthesis of essential oil and other secondary metabolites (Hafsi et al., 2014; Chrysargyris et al., 2017). Potassium also plays a particularly critical role in plant survival under different biotic and abiotic stresses (Wang et al., 2013).

Essential oil content and components of various medicinal and aromatic plants are influenced by the application of different rates of potassium fertilizer, but at adequate levels, it increases plant growth and essential oil production in medicinal plants. Under greenhouse conditions, different rates of potassium fertilizer (0.0, 0.5, 1.0, and 1.5 g K.dm^{-3}) were applied to basil plants. The results showed that applying adequate levels of potassium fertilizer (1.0 g K.dm^{-3}) produced maximum values of herbage yield, essential oil content, and L-ascorbic acid yield (Dzida et al., 2018). Under field conditions, basil plants were treated with four rates of potassium fertilizer (0, 50, 100, and 150 kg/ha), and applying an adequate level showed maximum values for different vegetative plant parameters (Matsumoto et al., 2013). However, Nurzyńska-Wierdak et al. (2012) reported that applying potassium fertilizer did not significantly increase the plant parameters and essential oil yield of basil grown under greenhouse conditions. In the case of sweet fennel (Foeniculum vulgare Mill.) plants grown under field conditions, the application of potassium fertilizer (potassium sulfate (48% K2O) source) in adequate rates (50-100 kg/ha) increased different plant parameters, including vitamin C, phenolic content, flavonoid content, and antioxidant capacity (Barzegar et al., 2020). A field study performed by Singh et al. (2014) showed the results of four rates of P fertilizer (0, 40, 80, and 120 kg K ha^{-1}) applied to lemon grass (Cymbopogon flexuosus) grown under field conditions. Statistical analysis showed that using an adequate level of potassium fertilizer (40 kg/ha) gave the maximum values of herbage yield and essential oil content.

Applying a high rate of potassium fertilizer increases the secondary metabolites in different medicinal and aromatic plants. Potassium in three rates (0, 200, and 400 mg/kg) was applied to basil plants grown under greenhouse conditions. The results showed that applying a high rate of potassium fertilizer increased the dry matter yield of basil, because potassium activated many enzymes in the plant that play a role in respiration and photosynthesis. However, utilizing an adequate rate of potassium fertilizer resulted in the maximum value of linalool in the essential oil of basil treated with 200 (mg/ka) compared with the other treatments (Esetlili et al., 2016). Under field conditions, two medicinal plants Cymbopogon citratus and Vetiveria zizanioides were treated with four rates of potassium fertilizer (0, 25, 50, and 75 kg ha^{-1}), and treatment with the highest rate of potassium fertilizer (75 kg/ha) resulted in the highest values of total biomass yield and essential oil content for both medicinal plants (Rashmi and Singh, 2008). In the case of fennel plants grown under field conditions, applying potassium fertilizer at a high level (30 kg K2O/fed) as potassium sulfate increased different plant traits, including seed yield and essential oil content (Younis et al., 2010). In general, using adequate levels of potassium fertilizer increases plant growth and essential oil yield and also reduces human and environmental issues. Moreover, high rates of P fertilizer applied to plants increases plant growth and essential oil yield, but the quality of the essential oil and other secondary metabolites will be poor compared with plants treated with adequate levels of P fertilizer.

Plant growth and the essential oil of medicinal plants are also influenced by the source of the potassium fertilizer. Different sources of potassium fertilizer (KCl, K_2SO_4, and KCl+K_2SO_4) were applied to basil plants grown under greenhouse conditions, and treatment with KCl+K_2SO_4 resulted in high values of different plant parameters, including essential oil content (Dzida et al., 2018). Applying potassium fertilizer in potassium sulfate form increased essential oil content as well as 1,8-cineole in the oil of basil grown under greenhouse conditions (Nurzyńska-Wierdak et al., 2013). Under field conditions, different sources of potassium fertilizer (control, KCl, K_2NO_3, and K_2SO_4) were applied to fennel, and the K_2NO_3 treatment showed the maximum values of vegetative plant parameters, seed yield, and essential oil content (Salama & Khater, 2020).

Influence of secondary macro-elements (Ca, S, and Mg) on growth and secondary metabolites production of various medicinal and aromatic plants

Sulfur, calcium, and magnesium are other macro-elements which are part of the secondary macronutrients group. Sulfur is the fourth major plant nutrient after nitrogen, phosphorus, and potassium that is required to increase plant growth and production of secondary metabolites of medicinal and aromatic plants (Ahmed et al., 2016). The essential oil production of different medicinal plants can be influenced by applying different rates of secondary macro-elements. Under field conditions, different rates of sulfur fertilizer (0, 50, and 100 kg ha^{-1}) were applied to arugula (Eruca sativa Mill.) plants. Applying a high rate of sulfur fertilizer resulted in the highest values of different leaf traits, seed yield, and yield components (Al-Mohammad & Al-Taey, 2019). In the case of Aloe vera plants grown under nursery conditions, applying different rates of sulfur fertilizer (0.0, 0.5, 1.0, 2.0, and 4.0 g/plant) showed that using the highest rate of sulfur fertilizer produced maximum values of leaf length, total number of tillers, root traits, shoot fresh and dry weight, leaf wight, and gel weight (Eisa et al., 2014). Under field conditions, different rates of sulfur fertilizer (0, 20, and 40 kg/ha) were applied to fennel plants, and utilizing a high rate of sulfur fertilizer (40 kg/ha) significantly increased plant height, total number of branches, total number of seeds, weight of 1000 seeds, and seed yield. However, the protein content was not increased by applying sulfur fertilizer (Kucha et al., 2019). An experiment carried out by Lal et al. (2014) on coriander (Coriandrum sativum L.) plants grown under field conditions showed that with three levels of sulfur fertilizer (20, 30, and 40 kg/ha) applied, applying the highest rate of S fertilizer (40 kg/ha) gave the maximum values of seed yield and yield components and also reduced the days of germination initiation and days of flowering. However, applying an adequate level of sulfur fertilizer (30 kg ha^{-1}) also increased seed yield and yield components of fenugreek (Trigonella foenum-graecum L.) plants grown under field conditions (Özyazici, 2020).

The source of sulfur fertilizer also influences plant growth and essential oil production of different medicinal plants. Two sources of sulfur fertilizer (agricultural sulfur and ammonium sulfate) were applied to dragonhead (Dracocephalum moldavica L.) plants grown under field conditions. Applying agricultural sulfur fertilizer increased essential oil content and the secondary metabolites more than applying ammonium sulfate (Aziz et al., 2010). An experiment performed by Khalid et al. (2009) on thyme plants grown under field conditions showed three levels of magnesium fertilizer (10, 20, and 30 g/L as magnesium sulphate ($MgSO_4$) source) applied as foliar applications.

Magnesium is another secondary macronutrient that is required by medicinal and aromatic plants grown under different environmental systems. The spray magnesium fertilizer at an adequate level (20 g/L) resulted in maximum values of different vegetative parameters, seed yield, essential oil content, and essential oil components. In the case of caraway (Carum carvi L.) plants grown under field conditions, the application of magnesium fertilizer led to increased plant growth and essential oil yield (Lizarazo et al., 2021).

Applying calcium fertilizer increased the plant growth and essential oil content of medicinal and aromatic plants. Calcium belongs to the secondary macro-element group that is required to improve the production of secondary metabolites by medicinal and aromatic plants grown under different environmental conditions. Under field conditions, different levels of calcium fertilizer (0, 5, and 10 t/ha) were applied to savory (Satureja hortensis L.) plants. Applying the adequate level (5 t/ha) of calcium fertilizer increased the fresh and dry weights of the herb. However, applying calcium fertilizer at different rates did not significantly increase essential oil content or rosmarinic acid yield (Babalar et al., 2010). Under greenhouse conditions, four rates of calcium fertilizer (0, 1.5, 3.0, and 4.5 t/ha) were applied on Chrysanthemum boreale plants. The treatment with 1.5 (t/ha) resulted in maximum values of different plant parameters, including total number of branches, flower yield, essential oil content, and mineral content in flower tissues (Lee & Yang, 2005). Summer savory (Satureja hortensis L.) plants grown under field conditions were treated with different rates of calcium fertilizer (0, 5, and 10 t/ha), and using the adequate rate showed maximum values of leaf area, leaf N content, and essential oil content (Mumivand et al., 2011). On the other hand, applying a high rate of calcium fertilizer can also increase plant growth and essential oil yield of medicinal and aromatic plants. Under nursery conditions, matricaria (Matricaria recutita L.) plants were treated with five rates of calcium fertilizer (0, 50, 100, 150, and 200 mg/pot). The application of a high rate of calcium fertilizer increased different plant parameters including total number of branches, total number of flowers, fresh weight of flower (g/plant), and essential oil content compared to other treatments (Upadhyay & Patra, 2011). However, applying a high rate of calcium fertilizer increased plant growth and essential oil yield, but the quality of the essential oil will be poorer than that achieved using an adequate level. Different rates of calcium fertilizer (0, 1.5, 3.0, and 6.0 g/L) were applied to French tarragon (Artemisia dracunculus L.) plants, and treatment with the high rate of calcium fertilizer increased vegetative traits, but it did not significantly increase essential oil content (Heidari et al., 2014).

Conclusion

Plant growth, essential oil content, and other secondary metabolites of different medicinal and aromatic plants grown under various environmental conditions can be modified based on the presence and availability of macronutrients. The participation of macronutrients in building different organic compounds in plants as well as the significant role of these macro-elements in the modification of secondary metabolites and essential oil content in medicinal and aromatic plants are vital. In different medicinal and aromatic plants grown under greenhouse or field conditions, nitrogen increases essential oil yield and its composition. Applying a high rate of nitrogen fertilizer increases the vegetative growth and essential oil content of some medicinal and aromatic herbs. It also decreases other compositions, such as the total phenolic contents, rosmarinic acid levels, and caffeic acid concentration in basil. In the cultivation of some medicinal and aromatic plants, a sufficient rate of phosphorus fertilizer contributes to an increase in plant growth and essential oil content and also increases essential oil composition, such as 1,8-cineole and linalool. Other macronutrients, such as potassium, sulfur, magnesium, and calcium, are also able to increase essential oil content and its composition for different medicinal and aromatic plants. The application of increased rates of macronutrients may contribute to the increase of essential oil yield in some medicinal and aromatic plants, but it causes certain changes in the essential oil composition. Moreover, applying a high rate of macronutrients may create several issues for human health as well as increase the risk of environmental pollution.

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