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Scientific principles for studying the soil requirements of the medicinal plant *Allium jesdianum* Boiss. & Buhse

Ali Rahimi[1*], Maryam Makkizadeh Tafti[2], Mahshid Rahimifard[2]

[1]Forests, Rangelands, and Watershed Research Department, Kohgiluyeh and Boyerahmad Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Yasouj, Iran. ORCID: https://orcid.org/0000-0001-5928-1554
[2]Research Institute of Forests and Rangelands, Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran
**Email: rahimi.ali1362@yahoo.com*

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Abstract

This study investigates the soil and nutritional requirements of the medicinal plant Allium jesdianum Boiss. & Buhse with a focus on the role of fertilizers and biofertilizers in improving growth and quality. The results showed that plants grown in soils treated with ammonium sulfate had higher concentrations of Fe, Mn, Zn, and B compared to those treated with calcium nitrate. Allium jesdianum was able to reduce rhizosphere pH through the release of organic acids and protons, facilitating nutrient uptake in alkaline soils. The application of mycorrhizal biofertilizers further enhanced nutrient absorption, especially phosphorus and micronutrients, and improved soil quality by contributing to physical, chemical, and biological balance. These findings highlight the importance of integrated nutrient management in promoting the yield, medicinal quality, and sustainability of Allium jesdianum cultivation.

Keywords: *Allium jesdianum* Boiss. & Buhse, Nutrition, Biological fertilizers, Calcareous, Medicinal plants, pH

Introduction

Allium jesdianum Boiss. & Buhse (Figure 1) is a biennial plant belonging to the Liliaceae family and native to Iran. Allium is a perennial, bulbous, flowering plant that grows wild in high mountains. The aerial parts of this plant are used to treat abdominal pain, rheumatism, vomiting, kidney stones, and colds (Mozaffarian, 2012). Medicinal plants are an alternative source of medicine because they contain saponins, alkaloids, flavonoids, etc., as well as minerals. The leaves used for decomposition have good mineral content, such as sodium, nitrogen, potassium, phosphorus, zinc, iron, copper, manganese, calcium, magnesium, and sulfur. Therefore, medicinal plants are not only used for therapeutic purposes, but they can also be used as food supplements (Manoj Kumar et al., 2021). Medicinal plants are a valuable source of insoluble dietary fiber and micronutrients. The amount of iron is between 0.043 to 422.5 mg/g, and the amount of zinc is between 0.04 to 14.8 mg/g. Ascorbic acid ranges from 0.31 to 7.035 mg/g in plants. Most of these plants are a good source of antioxidants and have high medicinal value against various diseases. However, some non-nutritive and anti-nutritive compounds are also part of such medicinal plants (Rehman & Adnan, 2018), Still, good production of high-quality medicinal plants depends on accurate knowledge of plant nutrient requirements (Yadegari, 2016).

Figure 1. *Allium jesdianum* Boiss. & Buhse

One of the essential, critical needs in agricultural planning to achieve high yield and optimal quality, especially in medicinal plants, is the evaluation of different plant nutrition systems. The correct method of increasing soil fertility and plant nutrition can improve the efficiency of inputs while preserving the environment, reducing erosion, and maintaining biodiversity (Mirzajani et al., 2019). Management of the use of chemical fertilizers is essential, critical in terms of environmental effects and quantitative and qualitative performance of medicinal plants, especially in arid and semi-arid regions of Iran (Mousavinik, 2012). In a study on the plant *Allium jesdianum* Boiss & Buhse, the results of the physical and chemical properties of the soil in the habitat and field showed that there was a significant difference at the 99% probability level ($p < 0.01$) in all the properties examined between the habitats and fields of the studied *Allium jesdianum* Boiss & Buhse. According to the results, Noorabad farm had a loamy texture and also had higher clay percentage and total nitrogen, manganese, iron, and copper values compared to other habitats, and there was a significant difference ($p < 0.01$). In the Kakarezha habitat, the percentage of sand, the percentage of organic carbon, phosphorus, and absorbable potassium had higher values than in other habitats. The percentage of clay and silt, EC, soil acidity, and zinc in the Meleh habitat had higher values compared to other habitats studied, and their differences were significant at the 99% probability level. In the Zalghi habitat, characteristics such as the percentage of organic carbon, nitrogen, phosphorus, potassium, manganese, and iron had lower values than in other habitats (Ramak et al., 2020). Nowadays, we need to use new agricultural techniques to reduce and eliminate the consumption of chemical inputs in agriculture and reduce their environmental risks. Especially for medicinal plants, among these techniques is the use of beneficial soil microorganisms under the title of biofertilizers to produce healthy agricultural products, (Dehghani-Meshkani et al., 2017), also based on the statements of (Eskandari et al., 2010), the low level of organic matter in agricultural soils has caused the excessive use of chemical fertilizers, especially nitrogen fertilizers, and the non-use of organic fertilizers in the last few years. Today, the excessive use of chemical fertilizers for the production of agricultural products has caused many problems, including adverse effects on the soil (salinity, pH, absorption of elements, etc.), soil microorganisms, surface and underground water pollution, and an increase in diseases in humans and animals. Therefore, the correct and optimal use of organic fertilizers for the production of healthy products free from toxins and chemical (organic) fertilizers is felt, which has a special place in the world markets, both in terms of the sales market and in terms of the right price. Organic farming ensures the continuation of sustainable agriculture and environmental quality; the absence of medicinal plants from chemical residues is necessary for their supply. One of the pillars of the sustainable agriculture system is the use of biological fertilizers to provide nutrients needed by plants, and to eliminate or significantly reduce them. It is in use that we can refer to vermicompost biological fertilizers, so it is possible to use alternatives to industrial chemical fertilizers, such as organic, green manure, animal fertilizers, and plant residues.

Material and methods

The author uses the results of the findings obtained from his previous studies and research related to herbal nutrition, and with the help and citations from the sites of related publications, books of other researchers, as well as evaluation and comparison using theories, ideas, on the topic of nutritional techniques of the medicinal plant *Allium jesdianum* Boiss. & Buhse in the agricultural systems of Iran have been discussed.

Results

With different methods, it is possible to find out the status of nutrients in *Allium jesdianum* Boiss. & Buhse plant. These methods are:

(1) Investigating the state of plant growth rate: by considering the rate of plant growth, it is possible to understand the state of nutrients in the plant. In soils with limited nutrients, the plant does not grow optimally, and this causes a decrease in the quantitative and qualitative yield of the product.

(2) Decomposition of plant organs such as leaves and fruit petiole: evidence has shown that 80 to 90% of the fresh weight of herbaceous plants is water, and of the remaining amount, approximately 95% of its dry weight is organic compounds, and the remaining 5% is mineral substances. The composition of plant ash depends on the age and type of the plant, the amount of fertilizer given and the soil environment. Most of the organic matter of the plant is carbohydrates, including cellulose in the cell wall. Therefore, hydrogen and oxygen are the most abundant elements in the dry matter of the plant. Since some plant organic molecules contain nitrogen, sulfur, and phosphorus. Therefore, the amount of these elements in the plant is relatively high. The decomposition of leaves is one of the accepted methods for identifying the nutritional requirements of plants. Leaf analysis is usually done in well-equipped water, soil, and plant laboratories using standard methods, and the obtained results are compared with the standard tables to determine the status of the plants in terms of the desired nutritional element (Kafi et al., 2005). The elements in dry matter are usually expressed in parts per million (ppm) or micrograms per gram. The analysis of many plants has shown that the amount of nitrogen is 40

to 60, potassium is about 20, and phosphorus and sulfur are 1-5.3 mg per gram of dry matter. These numbers are equivalent to 4-6% nitrogen, 2% potash, 15-3% phosphorus, and sulfur of dry matter. The amount of micronutrient elements such as iron, manganese, and zinc is usually between 20 and 200 micrograms per gram of dry matter. In contrast, iron has the highest amount, and zinc has the lowest amount. The amount of boron is about 20, copper is 5, and molybdenum is about one microgram per gram (mg per kilogram) of dry matter. The amount of minerals in plant ash depends on the type of plant. Usually, dicotyledonous plants have more calcium and magnesium than monocotyledons (Panahi Kordlaghri, 2011).

(3) Soil analysis (extraction): Preparation of saturated mud and preparation of extract from saturated mud is necessary to check the number of solutes and organic substances in the soil, the number of elements in the soil, and to determine the lack of essential elements in the soil for plant growth (Panahi kordlaghri, 2011).

(4) Investigating the increase in weight of soil microorganisms: The relative status of nutrients in the soil can be understood from the weight of soil microorganisms. Lack of oxygen reduces the absorption of nutrients by the plant from the soil in conditions where the soil lacks enough oxygen, such as when the soil is flooded or in swampy soils. Despite the presence of sufficient amounts of nutrients in the soil, the plant will not be able to absorb these elements. Also, actions such as stabilization of nutrients in the soil (fixation of phosphorus), insolubility of elements (formation of calcium phosphates or carbonates of zinc, iron, and calcium), or washing of nutrients (nitrogen and potassium) cause the plant to not have access to the required element (Panahi Kordlaghri, 2011).

In many Iranian soils, due to the amount of calcium carbonate and high pH, the soluble and absorbable form of most of the elements is less than the amount necessary for the proper growth and development of the plant (Norouzi et al., 2018). Soil pH is one of the most critical chemical characteristics of soil, which affects the physical, chemical, and biological characteristics of soil and in the activity of nutrients, solubility and transport of ions, oxidation and reduction reactions and ion exchange, activity of microbes, activity of roots and enzymes, and in Solubility and transport of ions is also effective (Norouzi et al., 2018). The pH of soils in most regions of Iran is considered calcareous. The high pH of these types of soils has resulted in the stabilization of nutrients and reduced their absorption by the plant (Shemirani et al., 2013). There has been an increasing interest in monitoring the nutrient composition and nutritional value of medicinal and aromatic plants in recent years. The results of variance analysis showed that the physical and chemical properties of the soil in different habitats of *Allium jesdianum* Boiss & Buhse had significant differences at the 1% level. The soil texture was different in different habitats of *Allium jesdianum* Boiss. & Buhse. The highest percentage of organic carbon and nitrogen was observed in the soil samples of the Vanai habitats of Boroujerd (3.5%) and Meleh Pol-e-Dokhtar (0.51%), respectively, and the lowest percentages were observed in the soil of the Zalqi habitats of Aligudarz (1.3%) and Kamandan-e-Azna (0.26%), respectively. The lowest (7.01) and highest (7.38) soil pH of the Ben Sorkh habitats were observed in the Parsk-e-Al-Shatar and Vanai regions of Boroujerd, respectively. The electrical conductivity (EC) of the soil in the studied locations ranged from 0.30 to 0.76 dS/m (Ramak & Asri, 2018). In a study, the levels of Bromine, copper, iron, zinc, manganese, and molybdenum in selected medicinal and aromatic plants were investigated. Examples of (chamomile), (nettle), (rosemary), (yarrow), (bay leaf), (St. John's wort), (basil), (lemon balm), (linden), (sage), and (thyme) were subjected to chemical analysis. The content of micronutrients in plant samples ranges from 3.2-15.6 mg/kg for copper, 3.93- 1057 mg/kg for iron, 53.6-22.3 mg/kg for zinc, and 28.3-148/mg/kg was observed for manganese/kg. 2.13 -23.0 kg for molybdenum and 15.0-64.3 mg/kg for Bromine (Acikgoz & Karnak, 2013), the results obtained are consistent with the data reported in other research (Panahi Kordlaghri, 2011) in Table 1. In a study to provide information that can improve the nutritional status, and productivity of fennel; the effect of two nitrogen fertilizers, ammonium nitrate, and ammonium sulfate, two nitrogen rates (60 and 90 N kg/ha), and two levels of micronutrients (without and with FeEDTA, MnEDTA and ZnEDTA were investigated on the growth, yield, and absorption of nutrients (N, P, K, Fe, Mn and Zn) in fennel plant. The results showed that ammonium sulfate at the level of 90 kg per hectare increased plant growth, dry matter production, and improved yield (shoots and leaves, onion and whole), the nutritional status of fennel improved, when ammonium sulfate at the level of 90 kg per hectare and foliar application of micronutrient mixture increased the absorption of macronutrients N, P, and K and micronutrients (iron, manganese, and zinc). The present study shows that foliar application of micronutrient elements can be an effective strategy in the biofortification of fennel plants with iron, manganese, and zinc to produce foliage and yield high nutritional quality (Hassan et al., 2015). Good production of high-quality medicinal plants depends on accurate knowledge of plant nutrient requirements (Yadegari, 2016). A study in Hungary showed that the use of 60 to

80 kg/ha of nitrogen, 40 to 60 kg/ha of phosphorus (P), and 80 to 100 kg/ha of potassium (K^+) led to an increase in the biological performance and phenolic compounds of the medicinal plant *Echinacea purpurea* L. (Ahmadi et al., 2020). The production of medicinal plants such as *Catharanthus roseus* showed a response to 20 kg K_2O/ha, and on the other hand, Ginger yield can be increased by using 150 kg K_2O/ha (Hosseini, 2012). Studies show that nitrogen, phosphorus, and potassium nutrients used in certain combinations increase yield rather than supplying each of the primary nutrients alone (Hosseini, 2012). The use of ammonium chemical fertilizers can cause major agricultural problems. Because the pH of the rhizosphere and the pH of the soil will decrease in the long term, this issue may mobilize potentially toxic ions such as aluminum and zinc and reduce the availability of required micronutrients. The pH of the rhizosphere is greatly affected by the source of nitrogen used by the plant, because nitrogen is a food element that is needed in significant quantities by the plant and can be absorbed in the form of a cation (ammonium) or an anion (nitrate). They must be electrically neutral. Therefore, when the plant absorbs more cations than anions, i.e., when ammonium is the primary source of nitrogen, compared to the case where nitrate is the primary source of nitrogen, and causes a slight increase in pH, it must expel more protons (to reduce the pH of the rhizosphere). Another reason for the reduction of rhizosphere pH when ammonium is used as a nitrogen source is that for every N that participates in the structure of amino acids, one H^+ is produced. Because ammonium is converted exclusively in the roots, while a part of nitrate is converted in the roots and another part in the leaves, the production of H^+ due to ammonium is much higher (Koucheki et al., 2007). Rhizosphere pH affects the availability of micronutrients as well as potentially toxic elements that are not necessary for plant growth (Figure 2).

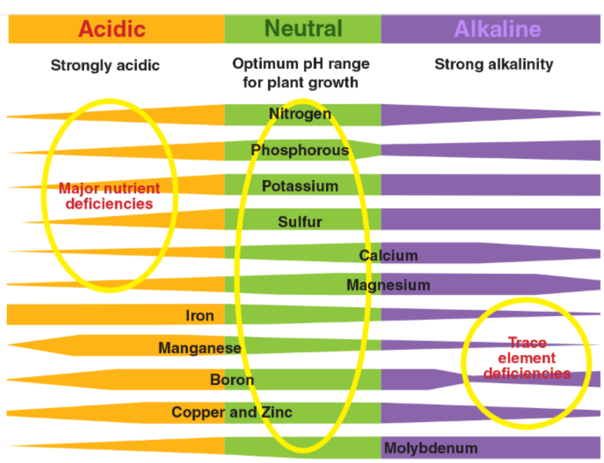

Figure 2. The effect of pH on the availability of soil nutrients

As the pH decreases, the availability of Zinc, Manganese, and bromine increases due to separation from soil particles. Manganese and iron are also more available due to reduction (respectively to Mn^{2+} and Fe^{2+}), and the availability of ferric iron (Fe^{3+}) also increases due to its higher solubility at low pH. In alkaline soils, with the application of ammonium, which causes the acidification of the rhizosphere, in comparison with the application of nitrate, which increases the pH around the roots, the symptoms of iron deficiency are removed. However, this is true when the inhibitor Nitrification, which prevents the microbial conversion of ammonium to nitrate, exists in the soil. Often, at high pH, net nitrification will increase due to the greater increase in nitrification compared to nitrate fixation by soil microbes. In practice, using iron in the form of chelates will be more effective. The availability of molybdenum decreases with increasing pH, while in the case of copper, due to the formation of complex compounds in the soil, it is not affected by pH. As a result, when plants are grown in soil fed with ammonium sulfate, the concentration of Fe, Mn, Zn, and Br in plant biomass will be higher than when fed with calcium nitrate. In materials (substrates) such as quartz sand, where manganese is found only in the form of Mn^{2+}, the pH drop in the rhizosphere may hurt, harm its absorption and concentration in the plant (Koucheki et al., 2016). Plants can greatly reduce the pH of the rhizosphere by releasing organic acids. The drop in pH also occurs due to the release of pure protons, because when the absorption of important cations, such as (K^+), is greater than that of anions, the release of H^+ is necessary to balance the electric charge. In alkaline soils, the acid secretion is to the extent that it lowers the pH of the soil. Some nutrient deficiencies cause plants to lower the pH of the rhizosphere. When its amount is insufficient, the plant reduces the pH of the root solution from 7 to 4. Zinc deficiency can also cause a drop in rhizosphere pH. Organic acids that adjust the iron solubility, especially when iron is in the form of $Fe (OH)_3$, play an important role in increasing the iron complex in the rhizosphere. Still, when the iron is present in the form of iron oxides (Fe_2O_3 and Fe_3O_4), it will play a lesser role in iron solubility. The decrease in pH in response to iron deficiency may coincide with an increase in iron reduction capacity at the root surface, due to the activity of a special reductase in the plasma membrane. Regenerating and chelating compounds (phenols) may be secreted and dissolve and regenerate Fe^{3+}. This reaction is characteristic of iron deficiency of dicotyledonous and monocotyledonous plants compared to grasses (strategy 1). The secretion of reducing compounds and chelates also increases the availability and absorption of manganese. In alkaline soils, where iron concentration is low and manganese is high, it may lead to manganese toxicity. When the buffering capacity of the soil is high and the pH is relatively high, strategy one will not be very effective (Koucheki et al., 2007). In arid and semi-arid regions, organic materials and acid-producing compounds are added to the soil to reduce pH. Elemental sulfur is one of the most important compounds in soil acidification (Norouzi et al., 2018). The researchers' findings so far have shown that the application of sulfur in the soil and its oxidation has caused a local decrease in pH in the rhizosphere region of the plant and an increase in the ability of the plant to absorb nutrients. For this purpose, an experiment was carried out under the title of investigating the effect of using sulfur and *Thiobacillus* bacteria on the performance of the vegetative body and the amount of essential oil of the Basil medicinal plant (*Ocimum basilicum* L.). The obtained results showed that the application of 500 kg/ha of sulfur fertilizer was significant for the characteristics of leaf and stem fresh weight, leaf and stem dry weight, leaf surface index, and essential oil percentage. Also, the effect of T*hiobacillus* bacterium inoculation on the above traits was significant. Among the levels of *Thiobacillus* bacteria, inoculation with bacteria was significant for all the mentioned traits except the stem dry weight. Also, the interaction effect of 500 kg of sulfur×Thiobacillus inoculation was significant only for the traits of essential oil percentage and leaf surface index (Rezvani Shemirani et al., 2014). So far, our results and discussion have been on the problem of pH in calcareous soils and its chemical modification by sulfur. However, this process (pH changes and improving the absorption of nutrients for medicinal plants) can be modified by the use of organic fertilizers. Vermicompost can be mentioned as one of the most desirable organic materials and biofertilizers, but the high consumption of vermicompost to achieve optimal performance and the presence of insoluble organic phosphates are limitations of vermicompost application. One of the ways to moderate the above limitations and increase the effectiveness of vermicompost is enriching it with plant growth-stimulating bacteria, especially with phosphate-dissolving bacteria. The results showed that using vermicompost enriched with phosphate-dissolving bacteria caused a significant increase in available phosphorus, soil microbial respiration, alkaline phosphatase enzyme activity, and dehydrogenase enzyme activity, and a decrease in pH compared to the control treatment. According to the final results, phosphate-dissolving bacteria were able to increase biological indicators and phosphorus availability, while the treatment enriched with *Serratia* *marcescens* bacteria had a greater ability to increase phosphorus availability and biological indicators, and vermicompost enrichment with bacteria Phosphate dissolver can be a suitable alternative to reduce the consumption of phosphate fertilizers and as a suitable strategy in the better management of vermicompost in calcareous soils in the future (Perastesh et al., 2019). In research, the effect of two micronutrients (Mn^{2+} and H_2Bo^{3-}) and macronutrients (PO_4^{3-} and NO_3^-) from biofertilizer sources (*Bacillus licheniformis*, *Nitroxin*, *Azospirillum* and *Azotobacter*) on growth (dry weight/wet leaf weight, dry weight/ root fresh weight, stem/root length, stem number), and essential oil accumulation in lemon balm (*Melissa officinalis* L.) were investigated. The most essential oils in the two seasons included caryophyllene oxide, E-caryophyllene, geranial, geraniol, chavicol, and neral, which were affected by the treatments. Among the two micronutrients, manganese and NO_3^- in macronutrients were more effective in stimulating the accumulation of components. At 150 ppm, micronutrients from biofertilizers increased the production of citronella and chavicol. Although the combination of H_2Bo^{3-}, and Mn^{2+} at 300 ppm was produced by macronutrients in some essential oils, such as neral, caryophyllene oxide, and 14-hydroxy-Z-caryophyllene, than the combination of 150 ppm, most of the essential oils were significantly increased in the concentration of micronutrients at 150 ppm. With the macronutrients Exo-Isocitral, Chavicol, 14-hydroxy-Z-Caryophyllene, and Germacrene D, micronutrients were extracted at a concentration of 150 ppm. Still, in many compounds of this essential oil, they were not extracted in a small concentration (Yadegari, 2016). Based on the experimental results, the biophosphate fertilizer in the treatment of 100 kg/ha had the best results in all the traits measured on the medicinal plant *Melissa officinalis*. Also, the best results were obtained using 10 tons of vermicompost per hectare in biological yield (4808.2 kg/hectare), essential oil percentage (0.13), and total chlorophyll (1.54 mg/gram of fresh leaves). According to the results of this research, the consumption of 100 kg of biological phosphate and 10 tons of vermicompost per hectare can provide suitable conditions to achieve the highest quantitative (5290 kg/hectare) and qualitative (0.26% essential oil) yield an lemongrass in a farming system. It was stable (Mirzajani et al., 2019). In an experiment that was conducted to investigate the effect of organic, biological, and chemical fertilizers on the absorption of nitrogen, phosphorus, potassium, seed yield, and essential oil in the anise (*Pimpinella anisum* L.), showed that the most nitrogen, phosphorus, potassium, and seed The chlorophyll of aerial parts was observed in the treatment of 10 tons per hectare of vermicompost. Also, the highest seed yield and essential oil yield were obtained in the fertilizer treatment of 10 tons per hectare of vermicompost. No significant difference was observed between the treatment of 10 tons of vermicompost and the integrated treatment of 5.7 tons per hectare of vermicompost and fertilization one and two on the trait of seed yield, and the lowest value was obtained for the above traits in the control treatment (no fertilizer use). According to the obtained results, it seems that the application of 7.5 tons of vermicompost treatment is the best treatment in the production of anise seed yield in the organic cultivation system (Behzadi & Salehi, 2016). So far, our discussion has focused on the direct uptake of mineral elements by the roots, but this process may be improved by mycorrhizal fungi symbiotic with the root system. The host plant provides carbohydrates for the mycorrhiza (from the Greek words mushroom and root) and receives water and nutrients from the mycorrhiza. Mycorrhizae are not uncommon and are scattered in natural conditions. In many plant communities, roots are associated with mycorrhizal fungi. 83% of dicotyledons, 79% of monocotyledons, and all fungi are usually associated with mycorrhizae. Mycorrhizal fungi have a combination of tiny tubular filaments called a hyphae complex (singular hyphae). The number of hyphae that make up the mushroom body is called mycelium. Two groups of mycorrhizal fungi important in absorbing mineral elements include *ectotrophic* mycorrhiza and vesicular-arbuscular mycorrhiza (Kafi et al., 2005). Ectotrophic mycorrhizal fungi usually form a thick sheath or mycelial covering around the root, and some of the mycelia penetrate the skin cells (Figure 1). The skin cells themselves are not captured by fungal hyphae, but instead are surrounded by a network of hyphae called Harting's network. The mushroom mycelium is so large that its total volume is equal to the roots themselves. The mycelium of the fungus also penetrates the soil, away from the dense covering of the fungus, and there they form hyphae or independent filaments containing reproductive organs. The capacity of the root system to absorb mineral elements increases due to the presence of external hyphae of the fungus, because they are much smaller than the roots of the plant and can reach the areas adjacent to the root and beyond the drained soil. Ectotrophic mycorrhizal fungi specifically infect tree species, including woody fungi and fungi. Unlike ectotrophic mycorrhizal fungi, vesicular-arbuscular mycorrhizal fungi do not produce a dense cover of fungal mycelium around the root. Instead, the hyphae of the fungus with a less dense arrangement grow both inside the root and towards the outside of the root. The soil next to it grows (Figure 3) (Kafi et al., 2005). After entering the root, the fungus hyphae penetrate not only into the space between the cells but also into the skin cells through the epidermis or root hair. Inside the cells, hyphae can form oval-like structures called vesicles and branches called arbuscules. It seems that the arbuscular is the place where elements are transferred from the fungus to the host plant. Outside the root, the external mycelium can extend several centimeters away from the root and possibly produce structures containing spores. In contrast to ectotrophic mycorrhiza, vesicular-arbuscular mycorrhiza produces a small mass of fungi, which rarely comprises more than 10% of the root weight. Vesicular-arbuscular mycorrhizae are found in the roots of most herbaceous species. The connection between the vesicular-arbuscular fungus and the plant root facilitates phosphorus absorption and trace metals such as zinc and copper. External myceliums also increase the absorption of phosphorus by expanding beyond the drainage area. Calculations have shown that the root associated with mycorrhizal fungi can transport phosphate more than four times that of the root without mycorrhiza. The external mycelium of ectotrophic mycorrhizae can also absorb and provide phosphate to the plant. In addition, it is believed that ectotrophic mycorrhizae reproduce in organic soil residues and break down organic phosphorus to be transferred to the roots (Kafi et al., 2005).

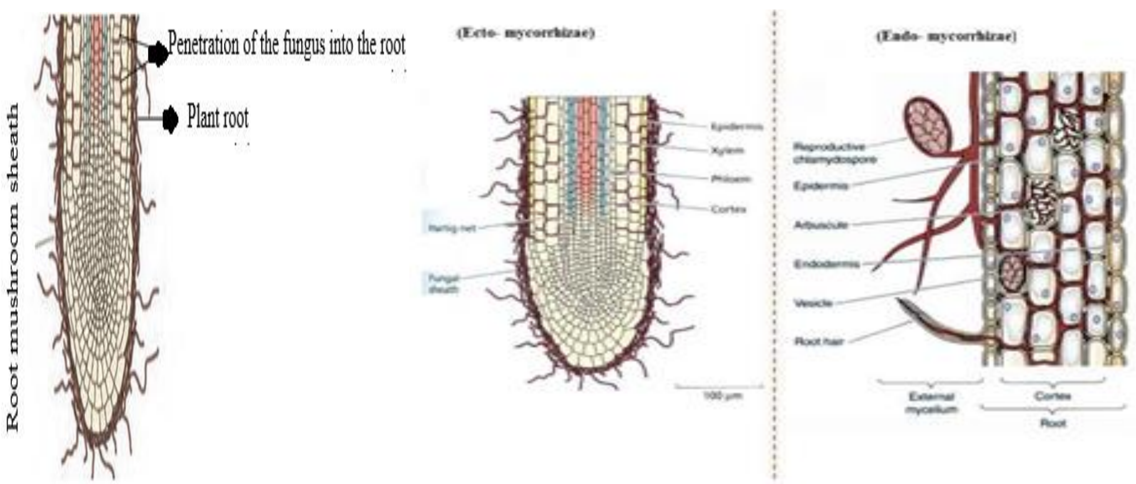

Figure 3. Roots are infected with ectomycorrhizal and endomycorrhizal fungi (vesicular-arbuscular) mycorrhizal fungi). In this infected root, the fungal hypha surrounds the root, creates a dense sheath, and penetrates the intercellular spaces of the skin, forming Harting's network. The total volume of the hyphae may be equal to the volume of the root itself.

Since mycorrhizal fungi increase the ability of the host plant to absorb phosphorus and mineral elements from the soil, especially from their inaccessible sources, therefore, these useful microorganisms are called biofertilizers and mycorrhizal fungi. They can be a suitable substitute for part of chemical fertilizers, especially phosphate fertilizers, in different ecosystems. The developed hyphae of mycorrhizal fungi can grow in the pores of the soil, which hairy roots and filaments are not able to penetrate; as a result, the plant's access to immobile elements such as phosphorus increases. In the symbiosis of mycorrhizal fungi with the host plant, part of the carbon resulting from the photosynthesis of the plant is available to the symbiotic fungus, and in return, the wide hyphal network of mycorrhizal fungi absorbs and transports water and mineral elements from the areas that are needed for the system. An inaccessible root accelerates the plant, and this symbiosis helps the plants to be able to grow in difficult conditions. The effect of mycorrhizal fungi is more evident, especially in lands where soluble phosphorus in the soil is lacking or due to drought stress, its diffusion coefficient has been greatly reduced. The growth rate of ectopic hyphae in fungi is, on average, 800 times the growth rate of the plant root system. Therefore, the phosphorus-free area around the hyphae of mycorrhizal fungi is formed in a more limited way than around the hairy roots. For this reason, more phosphorus is absorbed in the mycorrhizal symbiosis. Seed inoculation with mycorrhizal fungi increases the concentration of elements, especially phosphorus, in the plant, as a result of which their absorption efficiency increases, and the need to use chemical fertilizers decreases. The coexistence of mycorrhizal fungi with the host plant is important in terms of environmental issues and human and animal health. The use of biofertilizers of mycorrhizal fungi in the production of crops causes root development, improved growth, and increased yield of agricultural plants under abiotic stress conditions (Majidi and Amiri, 2013). Mycorrhiza has a beneficial effect in increasing the ability of the host plant to absorb immobile nutrients, especially phosphorus and several other micronutrients. Therefore, mycorrhizal fungi have a multipurpose function in agricultural ecosystems, so they can potentially improve the physical quality of the soil (through the expansion of fungal filaments), the chemical quality of the soil (through increasing the absorption of nutrients)) and soil biological quality (through the soil food web) (Veresoglou et al. 2012). In an experiment, the interaction of irrigation and mycorrhizal fungi on the phosphorus of *Borago officinalis* L. flowers was significant. Increase in flower phosphorus (44.69 and 20.45 percent), (150 and 125 percent) and (267.74 and 235.48 percent) under conditions of application of *Glomus mosseae* and *Glomus intraradices* compared to the absence of application of mycorrhizal fungi in irrigation levels were observed after 90, 120 and 150 mm of water evaporation from the evaporation pan, which created water stress for Borage. Of course, the absorption of nutrients from the soil solution is related to the state of soil water, so with the decrease in soil moisture, the diffusion flow of nutrients from the soil to the surface of the roots decreases. At irrigation levels, after 90-, 120-, and 150-mm evaporation of water from the evaporation pan can reduce soil moisture for the plant, and the results indicated that the use of mycorrhizal fungi probably reduces the negative effects of water stress by intensifying the microbial activity of the soil and absorbing phosphorus from the soil solution. It caused an increase in phosphorus in the plant's flowers under water stress conditions. Plant growth is not possible without phosphorus, and its increase can increase the leaf area index, height, number of branches, chlorophyll, and ultimately plant performance, and the increases of this element in the presence of mycorrhizal fungi application in water stress conditions increase the above traits as well, of course, a significant positive correlation was observed between phosphorus of Borage flower and leaf area index, chlorophyll and flower performance of Borage plant (Rahimi, 2017). Also, results showed that in water stress conditions, the application of the root fungus can be effective in modulating water shortage stress and increasing grain yield, biomass yield, thousand seed weight, oil percentage, and water consumption efficiency of Borage (*Borago officinalis* L.) compared to control plants (Rahimi et al., 2018). Mycorrhizal fungi *Glomus mosseae* and *Glomus intraradices* increased the amount of Borage phenol by 13% and 9%, respectively (Rahimi et al. 2016). Hyphae of mycorrhizal fungi can penetrate the tiny pores that even hairs cannot enter, and increase the amount of water absorption, at the studying, mycorrhizal fungi increased the relative water content of borage leaves under water stress conditions (Rahimi et al. 2017), as well as the use of both strains of mycorrhizae *Glomus mosseae* and *Glomus intraradices* in irrigation levels after 90, 120 and 150 mm of water evaporation from the evaporation pan, respectively, caused a significant increase in the flower harvest index of Borage plant (Rahimi, 2023). Drought stress reduces the absorption of nutrients by the roots and the transfer of these substances to the plant, which is due to the limitation of the transpiration rate, damage to the active transport, and reduction of membrane permeability. Absorption of nutrients from the soil solution is related to the soil water status, so that the diffusion flow of nutrients from the soil to the surface of the roots decreases with the decrease of soil moisture (Arndt et al. 2001). Probably, the use of biofertilizers has aggravating effects on the microbial activity of the soil and subsequently, by increasing the easy access of the phosphorus element in the soil for the plant, and also establishing the balance of these elements with the physical and chemical phases of the soil, the performance of the medicinal plant has improved. (Hosseini Mazinani and Hadipour, 2014). Based on the results of Soltanian and Tadyon's experiment (2007), the effect of drought stress on the amount of phosphorus in linseed was significant. Drought stress decreased phosphorus absorption. Mycorrhiza caused a significant increase in the studied trait. The interaction effect of mycorrhiza and drought stress on phosphorus content was significant. The symbiosis of linseed with arbuscular mycorrhizal fungi could increase the examined trait under drought stress conditions. The use of both types of mushrooms showed a greater effect than the absence of the use of mushrooms on the measured trait. The effect of the application of both species of *Glomus intraradices* and *Glomus mosseae* was almost the same. Jalil-vand et al. (2011) showed that drought stress had a significant effect on the amount of leaf phosphorus, and with the increase of drought stress, the amount of leaf phosphorus decreased. Inoculation with mycorrhizal fungi (*Glomus etunicatum* and *Glomus versiformis*) significantly increased the phosphorus content of plant leaves under drought stress conditions compared with non-inoculated plants. The research results showed that the mycorrhizal fungus *Glomus mosseae* caused an increase in the amount of phosphorus in the aerial parts of the medicinal plant, oregano, under drought stress conditions (Khaosaad et al. 2006). Drought stress had a significant effect on phosphorus absorption in Basil, so that with the decrease in soil moisture, the concentration of phosphorus in Basil plant roots decreased (Aslani et al., 2011). In addition, the effect of using arbuscular mycorrhizal fungi on phosphorus absorption was significant. The plants irrigated with arbuscular mycorrhizal fungi in comparison with non-irrigated plants, had more phosphorus in both drought stress and non-stress conditions. The effect of G. *mosseae* mushroom in reducing the drought effect is more than that of G. *mosseae* mushroom. It was G. *intraradices*. In the research conducted by Safir et al. 1971, 1972, the effect of mycorrhizal fungi on plant water relations was attributed to the direct effects of these fungi on the nutritional status of plant phosphorus. Still, numerous other reports show It shows that the effects of arbuscular mycorrhizal fungi on the water relations of the host plant can be independent of the nutritional status of phosphorus (Bethlenfalvay et al. 1998). According to reports (Deepadevi et al. 2010), in the application of the *Glomus fasciculatum* strain, the mycorrhizal fungus increased plant height and wet and dry yield of sorghum roots, which seems to be the reason for the ability of the mycorrhizal fungus to absorb phosphorus. In another study, G. *fasciculatum* and G. *macrocarpum* species increased the amount of phosphorus, manganese, and iron in the aerial parts and leaves of the heather (Chaudhary et al. 2007). Based on the results of research, it was found that the mushroom *Glomus etunicatum* has a positive effect on the growth and physiological parameters of the Basil medicinal plant, and this positive effect can be attributed to the improvement of the absorption of useful mineral elements in mycorrhizal plants (Sharifi et al., 2011).). In another study, the highest amount of phosphorus in safflower seeds was obtained in the inoculation treatment with *Glomus mosseae* and *Glomus intraradices* mycorrhizal fungi compared to the absence of mushroom inoculation (Omidi et al., 2014). A study showed that with the increase in drought stress, the amount of phosphorus in the plant leaves increased. Inoculation with mycorrhizal fungi significantly increased the phosphorus content of plant leaves under drought-stress conditions compared to non-inoculated plants (Ismaelpour et al., 2013). Jalil-Vand et al. (2011) showed that drought stress had a significant effect on the amount of phosphorus in the leaves of savory, and with the increase of drought stress, the amount of phosphorus in the leaves of the plant decreased. Inoculation with mycorrhizal fungi (*Glomus etunicatum* and *Glomus versiformis*) significantly increased the phosphorus content of plant leaves under drought stress conditions compared with non-inoculated plants. Research results showed that the mycorrhizal fungus *Glomus mosseae* caused an increase in the amount of phosphorus in the aerial parts of the medicinal plant, oregano (*Origanum sp., Lamiaceae*) under drought stress conditions (Khaosaad et al. 2006). The effect of G. *mosseae* mushroom in reducing the drought effect was more than that of G. *intraradices* mushroom. Based on the results of Soltanian and Tadayon's experiment (2015), the effect of drought stress on the phosphorus content of linseed was significant. Drought stress decreased phosphorus absorption, but mycorrhiza significantly increased phosphorus. The interaction effect of mycorrhiza and drought stress was significant, except for proline, sulfur concentration, and absorption, on the amount of phosphorus. The symbiosis of linseed with arbuscular mycorrhizal fungi increased the studied trait under drought-stress conditions. The application of both mushroom species showed a greater effect on the measured trait than the absence of application. The effect of the application of both species of *Glomus intraradices* and *Glomus mosseae* was almost the same. Therefore, according to the results of the research, it seems that water stress has caused a decrease in the phosphorus of different plants due to the decrease in the absorption of water and nutrients by the plant, and the mycorrhizal fungus due to the increase in the absorption of water and nutrients through the expansion of the mushroom threads. In the soil, the better transport of these materials in the plant organs has increased the phosphorus of different plants.

Conclusion

Nowadays, the excessive use of chemical fertilizers for the production of *Allium jesdianum* Boiss. & Buhse products have caused many problems, including adverse effects on the soil (salinity, pH, absorption of elements, etc.), soil microorganisms, surface and underground water pollution, and an increase in diseases in humans and animals. Therefore, the correct and optimal use of organic fertilizers for the production of healthy products free from toxins and chemical (organic) fertilizers is felt, which has a special place in the world markets, both in terms of the sales market and in terms of the right price. Organic farming ensures the continuation of sustainable agriculture and environmental quality. The absence of medicinal plants from chemical residues is necessary for their supply. One of the pillars of the sustainable agriculture system is the use of biological fertilizers to provide nutrients needed by plants with the aim to eliminate or significantly reduce. It is in use that we can refer to vermicompost biological fertilizers, so it is possible to use alternatives to industrial chemical fertilizers, such as organic fertilizers, green manure, and animal and plant residues. The use of biofertilizers of mycorrhizal fungi in the production of agricultural crops causes root development, improved growth, and increased yield of plants under abiotic stresses. Mycorrhiza has a beneficial effect in increasing the ability of the host plant to absorb immobile nutrients, especially phosphorus, and several other micronutrients. Therefore, mycorrhizal fungi have a multi-functional function in farm, farming, agrarian ecosystems, so they potentially improve the physical quality of the soil (through the expansion of fungal filaments), the chemical quality of the soil (through increasing the absorption of nutrients), and the biological quality of the soil (through the soil food web).

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References

Acikgoz, M. A., & Karnak, E. E. (2013). Micro-nutrient composition of some medicinal and aromatic plants commonly used in Turkey. Scientific Papers. Series A. Agronomy, 56, 169–173.

Ahmadi, F., Samadi, A., & Rahimi, A. H. (2020). Improving growth properties and phytochemical compounds of Echinacea purpurea (L.) medicinal plant using novel nitrogen slow-release fertilizer under greenhouse conditions. Scientific Reports, 10, 13842. https://doi.org/10.1038/s41598-020-70949-4

Arndt, S. K., Clifford, S. C., Wanek, W., Jones, H. G., & Popp, M. (2001). Physiological and morphological adaptations of the fruit tree Ziziphus rotundifolia in response to progressive drought stress. Tree Physiology, 21, 705–715.

Aslani, Z., Hosani, A. M., Rasouli Saedghiani, H., Sefidkan, F., & Barin, M. (2011). The effect of two species of arbuscular mycorrhizal fungi (Glomus mosseae and Glomus intraradices) on growth, chlorophyll levels, and phosphorus absorption in basil plant (Ocimum basilicum L.) under drought stress conditions. Iranian Journal of Medicinal and Aromatic Plants Research, 27(3), 471–486.

Behzadi, Y., & Salehi, A. (2016). The effect of using organic, biological and chemical fertilizers on the absorption of N, P, K elements, seed yield, and the yield of the essential oil of the medicinal plant Pimpinella anisum L. Iranian Journal of Medicinal and Aromatic Plants Research, 32(6), 1026–1036.

Bethlenfalvay, G. J., Brown, M. S., Ames, R. N., & Thomas, R. S. (1988). Effects of drought on host and endophyte development in mycorrhizal soybeans: Water use and phosphate uptake. Physiologia Plantarum, 72, 565–571.

Chaudhary, V., Kapoor, R., & Bhatnagar, A. K. (2007). Effects of arbuscular mycorrhiza and phosphorus application on artemisinin concentration in Artemisia annua L. Mycorrhiza, 17, 581–587.

Deepadevi, M., Basu, M. J., & Santhaguru, K. (2010). Response of Sorghum bicolor L. Moench to dual inoculation with Glomus fasciculatum and Herbaspirillum seropedicae. General and Applied Plant Physiology, 36(3), 176–182.

Dehghani Meshkani, M. R., Naqdi Badi, H. A., Rezazadeh, Sh. A., & Darzi, M. T. (2010). The effect of biological and chemical fertilizers on yield and components of flower yield in chamomile medicinal plant. Proceedings of the National Conference of Medicinal Plants. https://sid.ir/paper/819798/fa

Eskandari, M., Khaghani, Sh., & Gemarian, M. (2017). A review on the effect of vermicompost organic fertilizer on medicinal plants. Proceedings of the 8th National Conference on Medicinal Plants and Sustainable Agriculture, 21.

Hassan, M., Elwan, M., & Haggag, O. (2015). Plant growth, yield, macro and micro-nutrients uptake of fennel (Foeniculum vulgare Mill.) positively affected by N-sources and rates as well as foliar application of micronutrients. Hortscience Journal of Suez Canal University, 4(1), 7–16. https://doi.org/10.21608/hjsc.2015.6468

Hosseini, M. S. (2012). Macroelements nutrition (NPK) of medicinal plants: A review. Journal of Medicinal Plants Research, 6(12), 2249–2255.

Hosseini-Mazinani, S. M., & Hadipour, A. R. (2014). Improving the quantitative and qualitative performance of the medicinal plant Calendula officinalis L. by using biofertilizers. Quarterly Journal of Medicinal Plants, 15(2), 83–91.

Ismaelpour, B., Jalil-Vand, P., & Hadian, J. (2013). Effect of drought stress and mycorrhizal fungus on some morphophysiological traits and yield of savory (Satureja hortensis L.). Journal of Ecology, 5(2), 169–177.

Jalil-Vand, P., Esmaelpour, B., Hadian, J., & Rasulzadeh, A. (2011). Effect of drought stress and mycorrhizal fungus on the growth and secondary metabolites of savory. Proceedings of the 7th Congress of Horticultural Sciences of Iran, Isfahan University of Technology, 2.

Kafi, M., Zand, A., Sharifi, H. R., Guldani, M., & Lahuti, M. (2005). Plant physiology (translation). Academic Jihad Publications.

Khaosaad, T., Vierheilig, H., Nell, M., Zitterl-Eglseer, K., & Novak, J. (2006). Arbuscular mycorrhiza alters the concentration of essential oils in oregano (Origanum sp., Lamiaceae). Mycorrhiza, 16(6), 443–446.

Koucheki, A. R., Zand, A., Benaya Aval, M., Rezvani-Moghadam, P., Mahdavi Damghani, A. A., Jamial-Ahmadi, M., & Vesal, S. R. (2017). Plant ecophysiology (translation, 2 vols.). Ferdowsi University of Mashhad Publications.

Majidi, A., & Amiri, P. (2013). Biofertilizers of mycorrhizal fungi: A turning point in reducing the effects of environmental stresses in crop production. Quarterly Journal of Agricultural Engineering and Natural Resources, 11(42), 18–21.

Manoj Kumar, R., Puri, S., Pundir, A., Punia Bangar, S., Changan, S., Choudhary, P., Parameswari, E., Alhariri, A., Samota, M. K., Damale, R. D., Singh, S., Berwal, M. K., Dhumal, S., Bhoite, A. G., Senapathy, M., Sharma, A., Bhushan, B., & Mekhemar, M. (2021). Evaluation of nutritional, phytochemical, and mineral composition of selected medicinal plants for therapeutic uses from cold desert of Western Himalaya. Plants, 10(7), 1429. https://doi.org/10.3390/plants10071429

Mirzajani, M. R., Majidian, M., & Mohsen Abadi, G. (2019). Evaluation of the effect of combined nutrition on the quantitative yield and percentage of the essential oil of the medicinal plant Melissa officinalis. Plant Products, 42(4), 469–482.

Mousavinik, S. M. (2012). Investigating the effect of different levels of sulfur fertilizer on the quantitative and qualitative yield of the medicinal plant Plantago ovata L. under drought stress conditions in the Baluchistan region. Agricultural Ecology, 4(2), 170–182.

Mozaffarian, V. (2012). Identification of medicinal and aromatic plants of Iran. Moaser Publisher.

Nouruzi, S., Sohrabi, A., Khawazi, K., & Matinfar, H. R. (2018). The effect of sulfur consumption on the trend of pH changes and soil phosphorus absorption capacity in wheat (Triticum aestivum L.). Soil Biology, 6(1), 29–41.

Omidi, A., Mirzakhani, M., & Ardakani, M. R. (2014). Evaluation of quality traits of saffron (Carthamus tinctorius L.) under the application of Azotobacter and mycorrhizal symbiosis. Journal of Ecology, 6(2), 324–338.

Panahi Kordlaghari, Kh. (2011). Nutrition of agricultural plants. Nusuh Publications.

Perastesh, F., Alikhani, H. A., Etesami, H., & Hassandokht, M. R. (2019). The effect of vermicompost enriched with phosphate dissolving bacteria on the availability of phosphorus, pH and biological indicators in a calcareous soil. Electronic Journal of Soil Management and Sustainable Production, 9(3), 25–46.

Rahimi, A. (2017). The effect of mycorrhizal fungus on the physiological characteristics, active ingredients and yield of the medicinal plant borage (Borago officinalis L.) under water stress (Doctoral dissertation). Yasouj University.

Rahimi, A. (2023). The effect of mycorrhizal fungi, water stress, and year on flower yield and some characteristics of medicinal plant of borage (Borago officinalis L.) in Yasouj region. Journal of Plant Environmental Physiology, 18(4), 19–35.

Rahimi, A., Jahanbin, Sh., Salehi, A., & Faraji, H. (2016). The effect of mycorrhizal fungus on the morphological characteristics, amount of phenolic compounds, and chlorophyll fluorescence of the medicinal plant borage (Borago officinalis L.) under drought conditions. Plant Environmental Physiology, 11(42), 46–55.

Rahimi, A., Jahanbin, Sh., Salehi, A., & Faraji, H. (2017). Changes in content of chlorophyll, carotenoids, phosphorus, and relative water content of borage (Borago officinalis L.) under the influence of mycorrhizal fungi and water stress. Journal of Biological Sciences, 17, 28–34.

Rahimi, A., Jahanbin, Sh., Salehi, A., & Faraji, H. (2018). The effect of mycorrhizal fungus on seed yield, seed oil content, and water use efficiency of borage (Borago officinalis L.) under water stress conditions. Iranian Journal of Horticultural Sciences, 49(2), 407–415.

Ramak, P., & Asri, Y. (2018). Effect of growth degree days and soil properties on phenology and morphological characters of Allium jesdianum Boiss. & Buhse in Lorestan province. Journal of Plant Biological Sciences, 10(4), 35–52. https://doi.org/10.22108/ijpb.2018.110629.1093

Ramak, P., Karimian, V., & Siahmansour, R. (2020). Comparison of the nutrients and chemical composition of Allium jesdianum Boiss. & Buhse in the habitats and field. Iranian Journal of Horticultural Science, 51(1), 19–31. https://doi.org/10.22059/ijhs.2019.270402.1545

Rehman, A., & Adnan, M. (2018). Nutritional potential of Pakistani medicinal plants and their contribution to human health in times of climate change and food insecurity. Pakistan Journal of Botany, 50(1), 287–300.

Rezvani Shemirani, A., Haj Seyed Hadi, M. R., & Darzi, M. T. (2012). Investigating the effect of the application of sulfur and Thiobacillus bacteria on the performance of the vegetative body and the amount of essential oil of basil (Ocimum basilicum L.). Proceedings of the 13th Conference of

Agricultural Sciences and Plant Breeding of Iran & the 3rd Conference of Iranian Seed Science and Technology, Karaj. https://civilica.com/doc/312827

Safir, G. R., Boyer, J. S., & Gerdemann, J. W. (1971). Mycorrhizal enhancement of water transport in soybean. Science, 172, 581–583.

Safir, G. R., Boyer, J. S., & Gerdemann, J. W. (1972). Nutrient status and mycorrhizal enhancement of water transport in soybean. Plant Physiology, 49, 700–703.

Sharifi, M., Sadat Mohtashemian, M., Riyahi, H., Aghaei, A., & Alavi, S. M. (2011). The effect of endomycorrhizal fungus Glomus etunicatum on some morphological and physiological indicators of basil plant. Quarterly Journal of Medicinal Plants, 2(38), 85–94.

Soltanian, M., & Tadayon, A. (2015). The effect of symbiosis of arbuscular mycorrhizal fungi on some agricultural characteristics of linseed (Linum usitatissimum L.) under drought stress conditions in Shahrekord region. Plant Production Research Journal, 22(2), 24–42.

Veresoglou, S. D., Chen, B., & Rillig, M. C. (2012). Arbuscular mycorrhiza and soil nitrogen cycling. Soil Biology and Biochemistry, 46, 53–62.

Yadegari, M. (2016). Effect of micronutrient foliar application and biofertilizers on essential oils of lemon balm. Journal of Soil Science and Plant Nutrition, 16(3), 702–715.