



Enhancing Soil Fertility and Sweet Basil (*Ocimum basilicum* L.) Yield through the Synergy of Phosphorus Sources and Mycorrhizal Fungi

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Abstract

The excessive use of chemical fertilizers poses serious risks to food safety and environmental health. In contrast, natural and bio-fertilizers provide sustainable alternatives that enhance soil quality, nutrient availability, and crop productivity. In arid and semi-arid regions, phosphorus (P) deficiency and fixation further constrain agricultural output. Therefore, a field experiment was conducted over two consecutive growing seasons (2022 and 2023) to evaluate the effects of different phosphorus sources superphosphate (SP) and rock phosphate (RP) in combination with *arbuscular mycorrhizal fungi* (AMF) inoculation on soil chemical properties and the growth and yield of sweet basil (*Ocimum basilicum* L.). The experiment was arranged in a randomized complete block design with three replicates. Results indicated that all treatments significantly ($P < 0.05$) enhanced basil growth parameters, including plant height, number of branches, and both fresh and dry yields. The integrated application of phosphorus sources with AMF increased soil organic matter (SOM) and slightly elevated soil salinity (EC) compared with the control. Average increases in EC for SP + AMF (T_2) and RP + AMF (T_3) treatments were 23.53% and 4.26%, respectively, while SOM increased by 4.98% and 28.11% relative to the control (T_1). Available phosphorus content also rose significantly ($P < 0.05$) by 18.58% and 41.05% under T_2 and T_3 , respectively, compared to T_1 . Fresh yield increased by 22.30% and 19.28%, while dry yield rose by 26.86% and 24.17% under T_2 and T_3 , respectively, relative to the check treatment. These findings demonstrate that integrating phosphorus fertilizers with *arbuscular mycorrhizal fungi* can enhance soil fertility, nutrient availability, and sweet basil yield, offering a sustainable approach to reduce dependence on chemical fertilizers.

Keywords: *Ocimum basilicum*, AMF, calcium superphosphate, rock phosphate, sustainable agriculture.

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1. Introduction

Medicinal and aromatic plants hold significant economic value due to the persistent and growing demand for their products in both domestic and international markets [1-2]. Basil is regarded as one of the most significant medicinal plants. Basil stands out as a widely recognized aromatic plant that serves as a viable alternative crop due to its significance across various domains, including nutrition, economics, medicine, and industry [3-5]. Furthermore, Medicinal plants are a large and diverse group of plants that have been used as herbal medicines for the prevention and treatment of a variety of diseases since antiquity [6]. Sweet basil (*Ocimum basilicum* L.), an aromatic annual herb, belongs to the Lamiales family. Basil has pharmacological qualities and is utilized in medicine due to its high concentration of flavonoids, phenolic compounds, essential oils, and chemicals with antibacterial, antimycotic, and antioxidant qualities. When combined with vitamin E, rosmarinic acid, the primary phenolic molecule in basil, has the highest level of antioxidant activity. Basil leaves also contain trace amounts of other phenolic chemicals, such as ferulic acid and castic acid [7-9]. Additionally, basil, an annual plant

indigenous to India, is grown worldwide, especially in Asia, Africa, and the Mediterranean region of Europe. Phosphorus is a crucial nutrient for plants, second only to nitrogen.

P availability in soils is limited due to its fixation as insoluble phosphates of Al, Fe and Ca, particularly in calcareous soils. The conventional method to address phosphorus limitation involves the application of substantial quantities of phosphorus fertilizers to the soil. Due to the high phosphate-binding capacity of soils, plants utilize only 10–25% of the phosphorus applied from fertilizers [10]. In addition, soil reaction (pH) is one of the most important parameters which point the overall changes in the soil chemical characteristics. pH helps in preserving soil fertility and to keep equilibrium among soil nutrients availability [11]. In the same context, observed that the conventional use of phosphate rock as a phosphate fertilizer is limited by soil pH because phosphate rock requires acidic conditions for effective dissolution and phosphorus availability to plants. In Egypt, where cultivated soils typically have an alkaline pH range of 7.8 to 8.2, phosphate rock application is generally unsuitable without amendments because such high pH conditions reduce its solubility and thus its fertilizer

effectiveness [12], soluble phosphorus fertilizers readily precipitate into insoluble forms. There is an information deficiency on combination use of natural & organic fertilizers instead of chemical ones in order to obtain clean food. Our hypothesis is to use organic waste alone or combined with natural fertilizers may have a beneficial effect on soil properties, plant growth enhancement, nutrient uptake than using chemical fertilization [13].

Because of its low availability and poor recovery from applied fertilizers, phosphorus is the least accessible macronutrient and, as a result, the most commonly deficient nutrient in the majority of agricultural soils, despite its significance in plant development and metabolism. Additionally, the low recovery of phosphorus from fertilizers is attributed to its primary adsorption by the soil, rendering it unavailable for plant uptake [14]. A comprehensive understanding of phosphorus-use efficiency is essential for optimizing phosphorus management, with the objective of minimizing chemical phosphorus fertilizer consumption and maximizing the utilization of the biological potential of root and rhizosphere processes for effective mobilization and acquisition of soil phosphorus by plants [15]. Bio-fertilizer is an important source to plant, which has a significant effect on increasing plant growth and improving soil properties [16]. The bio-fertilizers substances containing microorganisms that can convert inert nutrients into useful forms through biological processes [17], then led to increase plant growth through a variety of mechanisms, including nitrogen fixation, improved nutrient absorption, production of organic acids, nutrient solubilization, defense against plant pathogens, and excretion of growth-stimulating hormones like IAA & GA₃, which promoted growth and produced a high yield [18].

Also, increasing soil organic matter content, improves soil's physical, chemical, and biological characteristics, and it increases nutrients availability, particularly phosphorus [13-19-21]. Moreover, *Arbuscular mycorrhizal fungi* (AMF) are essential components of the microbial colony, which has a close symbiotic relationship with plant roots. It uses plants to effectively uptake soil nutrients that are useful for plant growth and development and increase yield production. This is achieved by using organic compounds that strengthen the interaction between AMF and plants. AMF have both positive and negative impacts on rhizosphere fungal structures [22-23]. There is a significant improvement in the absorption of some macronutrients such as N, P, K Ca, and Mg by plants after inoculation with AMF [24-25]. Additionally, the utilization of beneficial microbes, such as arbuscular mycorrhizal fungi (AMF), to enhance phosphorus solubility and crop productivity is garnering increased interest in agricultural sustainability [26-27]. *Arbuscular mycorrhizal fungi* from phylum *Glomeromycota* are acknowledged for establishing symbiotic relationships with the roots of over 80 % of terrestrial plant species [28].

This category also includes medicinal plants [29-30]. The symbiotic relationship between plants and soil allows them to extract a greater quantity of water and essential mineral nutrients, such as phosphorus, nitrogen, and minor elements. In return, the AMF absorbs photo-assimilates (i.e., carbohydrates and vitamins) from the host plant [31-33]. AMF enhance the absorption of poorly mobile or immobile mineral ions from the soil through the extension of their hyphae beyond the rhizosphere, thereby augmenting the root's surface area for absorption [34]. This study aims to

evaluate the impact of superphosphate and rock phosphate when applied with *arbuscular mycorrhizal fungi* (AMF) on soil properties, nutrient availability, and the growth and yield of sweet basil. A key objective is to determine the potential for partially replacing chemical fertilizers with these natural alternatives. The research also focuses on the role of AMF in phosphorus solubilization and plant quality improvement, with a view toward commercializing AMF-based bio-fertilizers for sustainable phosphorus management.

2. Materials and Methods

2.1. Experimental Site and Design

The field experiment was conducted over two consecutive summer seasons (2022 and 2023) at a private farm located in Edfo Center, Aswan Governorate, Egypt. The experimental site is characterized by clay loam soil. Prior to the initiation of the experiment, representative soil samples were collected from the surface layer (0-30 cm) to determine the soil's physical and chemical characteristics. These analyses were performed on air-dried samples using standard procedures. The main physicochemical properties of the soil are presented in Table (1).

2.2. Plant Material, Inoculation, and Experimental Layout

Seeds of sweet basil (*Ocimum basilicum* L.) were obtained from the Medicinal and Aromatic Plants Research Department, Agricultural Research Center (ARC), Giza, Egypt. *Arbuscular mycorrhizal fungi* (AMF) inoculants were supplied by the Bio-fertilizer Production Unit, Soil, Water and Environment Research Institute, ARC, Giza, Egypt. For inoculation, basil seeds were coated with the *Arbuscular Mycorrhizal Fungi* (AMF) inoculum using 40% Arabic gum as an adhesive agent. The coated seeds were allowed to dry and were sown within three hours of inoculation to ensure inoculum viability. The experiment was arranged in a randomized complete block design (RCBD) with three replicates. Each experimental plot measured 3.0 × 3.5 m and consisted of three rows spaced 50 cm apart. Seeds were sown on one side of the rows, with hills spaced 25 cm apart (12 plants per row, equivalent to approximately the 24,000 plants per feddan). Sowing was carried out in mid-April during the 2022 season and on the April 20th during the 2023 season. Three harvest cuts were taken from each plot at 45-day intervals until the final harvest, which occurred on the September 1st in the first season and on the September 5th in the second season.

2.3. Plant Measurements and Yield

The following growth and yield parameters were recorded: plant height (cm), number of branches per plant, and fresh and dry weight yields (tons per feddan). These measurements were used as indicators of vegetative growth performance. According to the recommendations of the Egyptian Ministry of Agriculture and Land Reclamation, the following fertilizer doses were applied: 125 kg N/feddan in the form of ammonium sulfate (20.5% N) and 50 kg K/feddan in the form of potassium sulfate (48.5% K₂O). The total quantities of ammonium sulfate and potassium sulfate were thoroughly mixed and divided into two equal portions. The first dose was applied 15 days after transplanting, and the second dose was applied 20 days after the first cut. All treatments received the same nitrogen and potassium fertilizer schedule.

2.4. Treatments of the Experiment

According to the recommendations of the Egyptian Ministry of Agriculture and Land Reclamation, phosphorus was applied at a rate of 45 kg P/feddan (126 kg P/ha). The phosphorus was supplied from either rock phosphate (30 % P₂O₅) or superphosphate (15.5 % P₂O₅), applied individually or in combination with *arbuscular mycorrhizal fungi* (AMF). Phosphorus fertilizers were incorporated into the soil during land preparation and thoroughly mixed into the topsoil immediately before planting. The experimental treatments were as follows: **T₁**: Inoculation with AMF only (check treatment), **T₂**: Superphosphate (126 kg P/ha) + AMF, and **T₃**: Rock phosphate (126 kg P/ha) + AMF. At each harvest (first, second, and third cuts), basil plants from every treatment were collected separately during both the 2023 and 2024 growing seasons. The harvested plants were air-dried in a well-ventilated, shaded area to prevent direct exposure to sunlight. Samples were then oven-dried at 70 °C until a constant weight was reached, and the dry yield was recorded. Random dried samples were ground and stored in airtight containers for subsequent chemical analyses.

2.5. Soil and Plant Analysis

Soil texture was determined using the pipette method, while soil reaction (pH) was measured potentiometrically according to [35]. Soil salinity (EC) and calcium carbonate (CaCO₂) content were assessed following the procedures described by [36]. Available phosphorus (P) was extracted using 0.5 N NaHCO₃ according to [37] and quantified spectrophotometrically at 660 nm. Available potassium (K) was extracted using 1 N ammonium acetate and measured with a flame photometer, following [38]. Available nitrogen (N) was extracted at a 1:5 soil-to-solution ratio using 1% K₂SO₄, and 20 mL of the extract were distilled using the micro-Kjeldahl method with the addition of 1 g of Devarda's alloy [38]. Soil organic matter (SOM) was determined by oxidation with, K₂Cr₂O₇ and H₂SO₄ as described by [38]. For plant analysis, 2.0 g of dried basil plant material were digested using a mixture of H₂O₂ and H₂SO₄. The digests were analyzed for total nitrogen (N), phosphorus (P), and potassium (K) following the standard procedures of [36]. In another procedure, the dried and ground plant samples were digested using a sulfuric-to-perchloric acid mixture (7:3 ratio) to determine nutrient contents, and total N, P, and K were subsequently quantified. The essential oil content in fresh basil herb was determined during both seasons using the hydro-distillation method with a Clevenger-type apparatus, as described by [39].

2.6. Statistical Analysis

Data were statistically analyzed using analysis of variance (ANOVA) to evaluate the significance of differences among treatments. Means were compared using Duncan's Multiple Range Test (DMRT) at the 5% probability level. All statistical analyses were performed using CoStat software [40].

3. Results and discussion

3.1. Results

3.1.1. Effect of Different P-sources with AMF on Some Soil Chemical Properties

In the present study, the chemical properties of soil after harvesting sweet basil plants treated by different P-

sources; superphosphate (SP) or rock phosphate (RP) in combination with *arbuscular mycorrhizal fungi* (AMF) general some soil chemical properties such as electrical conductivity (EC), soil reaction (pH), and soil organic matter (SOM) were significantly ($p \leq 0.05$) affected due to different combinations in fertilizers treatment applications in the two growing seasons 2023 and 2023 (Table 2). A significant decrease in soil salinity (EC) was observed in these treatment groups. In contrast, they led to a non-significant rise in soil pH and a significant increase in soil organic matter (SOM) compared to the check treatment (T₁). The combined application of both phosphorus sources with AMF was particularly effective in enhancing SOM and pH, despite the associated reduction in EC. On average, across both seasons, soil salinity (EC) relatives increased by 23.53 and 4.26 % for T₂ and T₃, respectively, above the check treatment. Conversely, SOM content relatives increased by 4.98 and 28.11% for the same treatments (T₂ and T₃) average two seasons. In general, the values of EC in the soil under the superphosphate treatments were higher than the rock phosphate with AMF treatments. Furthermore, the addition of SP or RP with AMF significantly ($P < 0.05$) increased the available phosphorus (P) in the soil compared to the check. Treatment T₃ (RP combined with AMF) resulted in the highest available P, with average increases of 18.58 % for T₂ and 41.05% for T₃ over the check treatment (T₁) in two seasons, respectively.

3.1.2. Effect of Different P-sources with AMF on Growth and Yield of Sweet Basil Plants

The influence of bio-fertilizer *Arbuscular Mycorrhizal Fungi* (AMF) combined with different phosphorus sources on the growth and yield of sweet basil plants is presented in Figures 1 and 2. The recorded growth characteristics plant height (PH) and number of branches (NB) were significantly increased ($P < 0.05$) across the first, second, and third cutting by the application of AMF with either superphosphate (SP) or rock phosphate (RP) during both growing seasons. The combined treatments, involving both AMF inoculation and phosphorus fertilization, demonstrated a superior effect in enhancing these growth parameters compared to individual applications. This synergistic effect was consistent over multiple harvests, underscoring the benefit of the integrated approach for improving sweet basil productivity. The application of a full recommended dose of calcium superphosphate (T₂) in combination with *arbuscular mycorrhizal fungi* (AMF) resulted in the most significant enhancement of vegetative growth traits across three harvests and both growing seasons. This was followed by the treatment with 100% rock phosphate and AMF (T₃), with both outperforming the application of AMF alone. Vegetative growth, specifically plant height and the number of branches, increased progressively with each successive harvest. This trend was most pronounced following the third harvest, particularly in the T₂ treatment (calcium superphosphate + AMF). The T₂ treatment produced the highest values for plant height and branch number per plant in all harvests Figures 1 and 2. Plant height in the T₂ group increased by 30.56, 37.40, and 26.57 % over the check treatment in the first, second, and third harvests, respectively. Similarly, the number of branches increased by 37.40, 37.40, and 36.25 % across the same harvests compared to the check.

3.1.3. Effect of Different P-sources with (AMF) on N, P and K-contents in Sweet Basil Plants

Data presented in Table 3 indicate that the combined application of phosphorus fertilizers and *arbuscular mycorrhizal fungi* (AMF) significantly enhanced the nitrogen (N), phosphorus (P), and potassium (K) content in sweet basil plants. Specifically, the addition of either superphosphate (SP) or rock phosphate (RP) along with AMF during both growing seasons positively and significantly ($p < 0.05$) influenced NPK contents in sweet basil. The integrated treatments combining microbial inoculation and phosphorus fertilization proved more effective in improving these nutritional parameters compared to individual applications. Among these, the treatment with 100% of the recommended chemical phosphorus fertilizer (T_2) in the presence of AMF resulted in the most significant improvement in N, P, K, and essential oil content across all three harvests and both seasons. Notably, the concentration of N, P, and K increased progressively with each successive harvest. The highest phosphorus content was recorded in plants treated with superphosphate and the AMF (T_2), which showed increases of 32.01, 34.34, and 36.22% in the first, second, and third cuts, respectively, compared to the control (T_1). Similarly, the same treatment (T_2) significantly enhanced the essential oil content of basil plants, with recorded increases of 35.97, 35.61, and 34.68 % for the first, second, and third cuts, respectively, relative to the untreated control.

3.1.4. Effect of Different P-sources with AMF on Fresh and Dry Weight Yields of Sweet Basil

The combined effect of different phosphorus sources and *arbuscular mycorrhizal fungi* (AMF) inoculation on the fresh and dry weight yields of sweet basil plants is presented in (Figure 3). Results indicated a highly significant increase ($p < 0.05$) in both the total fresh weight yield across two growing seasons and the dry weight yield of basil plants following the application of superphosphate (SP) or rock phosphate (RP) in the presence of AMF, compared to the control treatment. Averaged relative increased across both growing seasons, the fresh weights of basil yield were 8.27 and 7.95 (ton/fed.) for T_2 (superphosphate + AMF) treatment and T_3 (rock phosphate + AMF), respectively. These values represent increases of 22.30% and 19.28% over the check treatment (T_1). Similarly, the dry weights of basil yield were 2.15 and 2.08 (ton/fed.) for T_2 (superphosphate + AMF) treatment and T_3 (rock phosphate + AMF), corresponding to increases of 26.86 and 24.17%, respectively, over the check treatment (T_1). Additionally, basil yields were generally higher in the second season 2024 than in the first season 2023 across all treatments.

3.2. Discussion

Phosphorus (P) is a vital plant nutrient, second only to nitrogen in its importance. However, its availability in soils particularly calcareous types is often limited due to fixation into insoluble compounds of aluminum, iron, and calcium [10-21]. While, conventional agriculture addresses this through heavy application of chemical phosphorus fertilizers, we hypothesized that the use of organic amendments, either alone or in combination with natural fertilizers, could more beneficially influence soil properties, plant growth, and nutrient uptake compared to chemical fertilization alone [13]. Enhancing soil organic matter (SOM) is key in this regard, as

it improves the soil's physical, chemical, and biological properties and increases nutrient availability, particularly for phosphorus [13-19-21]. Consistent with this, our study found that the addition of superphosphate (SP) or rock phosphate (RP) in combination with *arbuscular mycorrhizal fungi* (AMF) significantly increased SOM compared to the check treatment. While, it was led to slight increase non-significant it soils reaction (pH) and negative significant effect on soil salinity (EC). The increases in the results such as EC, OM and available-P may be due to addition bio-fertilizers and mixture with phosphorus sources, led organic matter decomposition and the secretion of organic acids in soil, moreover, at organic acids to the accelerated dissolution of rock phosphate and the release of excess salts into the soil solution.

Furthermore, biologically it consolidates the development of soil organisms, while chemically it acts as an adsorption and retention complex for inorganic plant nutrients. Finally, it increases the available-P for the crop plants. This result is similar to what was mentioned [13-41] indicated that the activity of microorganisms that generate organic acids and CO_2 during organic matter decomposition to the accelerated dissolution of rock phosphate and the release of excess salts into the soil solution, with this effect intensifying as the quantity of rock phosphate applied increases, which led to an increase in EC of soil. The integration of bio-fertilization (AMF) with either SP or RP also significantly ($P < 0.05$) enhanced plant height and branch number in sweet basil during both seasons. This synergistic effect the combined treatments, likely stems from heightened microbial activity that boosts nutrient mineralization and availability demonstrate greater effectiveness in enhancing in the parameters; the increase may be due to increased microbial activity resulting from the addition of bio-fertilizer with different phosphorus sources, which led to increased release of nutrients. Our findings align with [42], who reported that AMF improves plant growth and nutrient uptake in low-fertility soils and enhances the efficiency of applied phosphorus fertilizers.

Similar observations were noted by [43-44], who found that mycorrhizal associations improve water and nutrient absorption, leading to better plant performance. [45] also recorded significant yield increases in black cumin following AMF inoculation. Moreover, the combined application of the full recommended dose of chemical P-fertilizer (T_2) with AMF significantly boosted nitrogen, phosphorus, potassium, and essential oil content (%) in across three cuts during both seasons to basil plants. This improvement in nutrient content can be ascribed to the role of AMF in solubilizing phosphorus and facilitating the absorption of other nutrients, thereby promoting root development and enhancing the plant's capacity to acquire soil nutrients. This result is similar to what was mentioned by [44-47]. The observed increased oil content may be attributed to the presence of sulfur in calcium super phosphate, which plays a crucial role in the synthesis of fatty acids or it may be due to the addition of bio-fertilizer trichomes specialized exterior secretory structures that emit secondary metabolites. This result is consistent with what was mentioned by [48-50]. Sulfur also plays a critical role in amino acid production, such as cysteine and methionine, further supporting the plant metabolic functions and oil production.

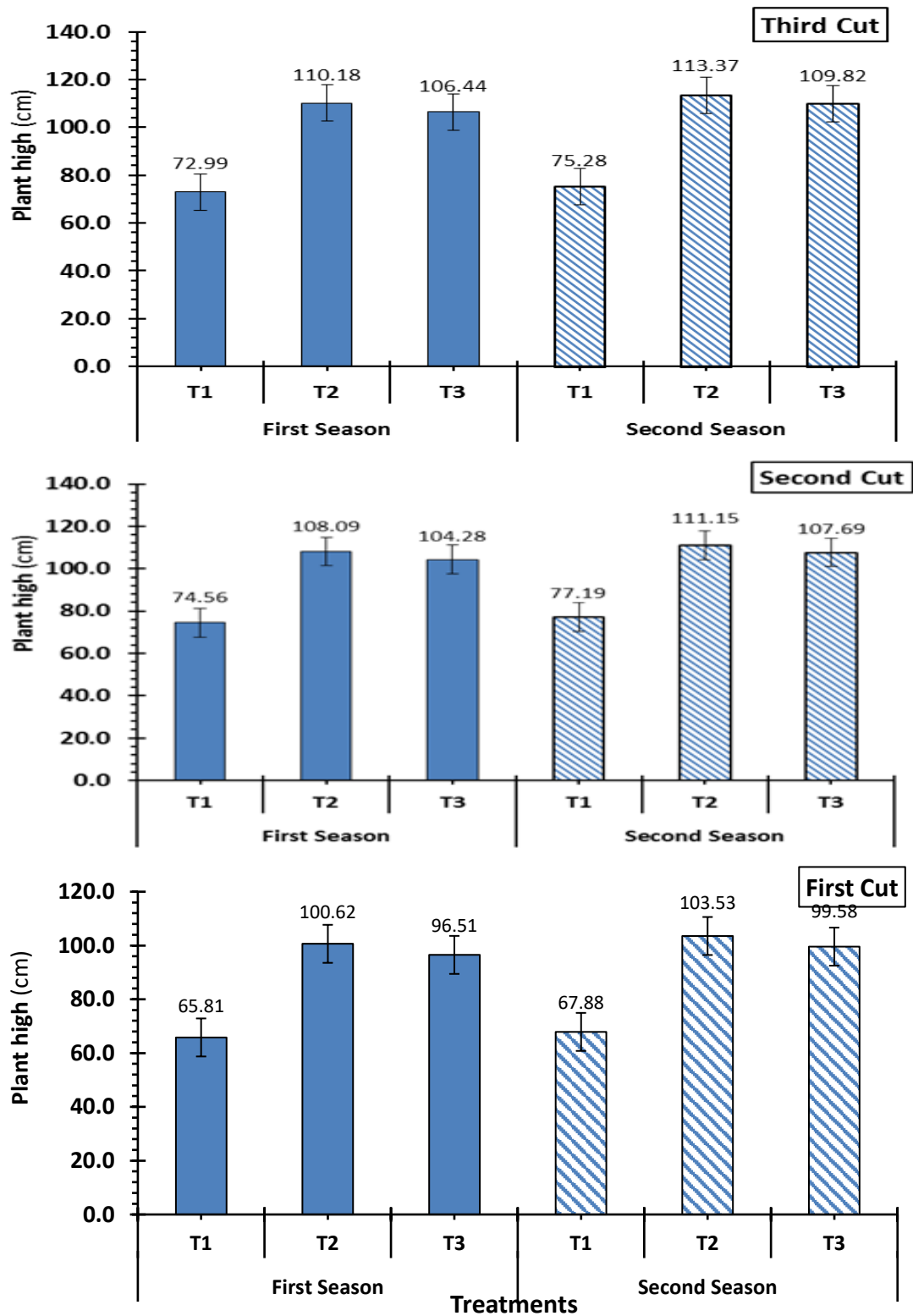


Fig. 1: Effect of combined different P-sources with AMF on plant high of sweet basil during three cutting in both seasons T₁= (check treatment), T₂=super phosphate + *arbuscular mycorrhizal fungi* (AMF) and T₃= rock phosphate+ *arbuscular mycorrhizal fungi* (AMF).

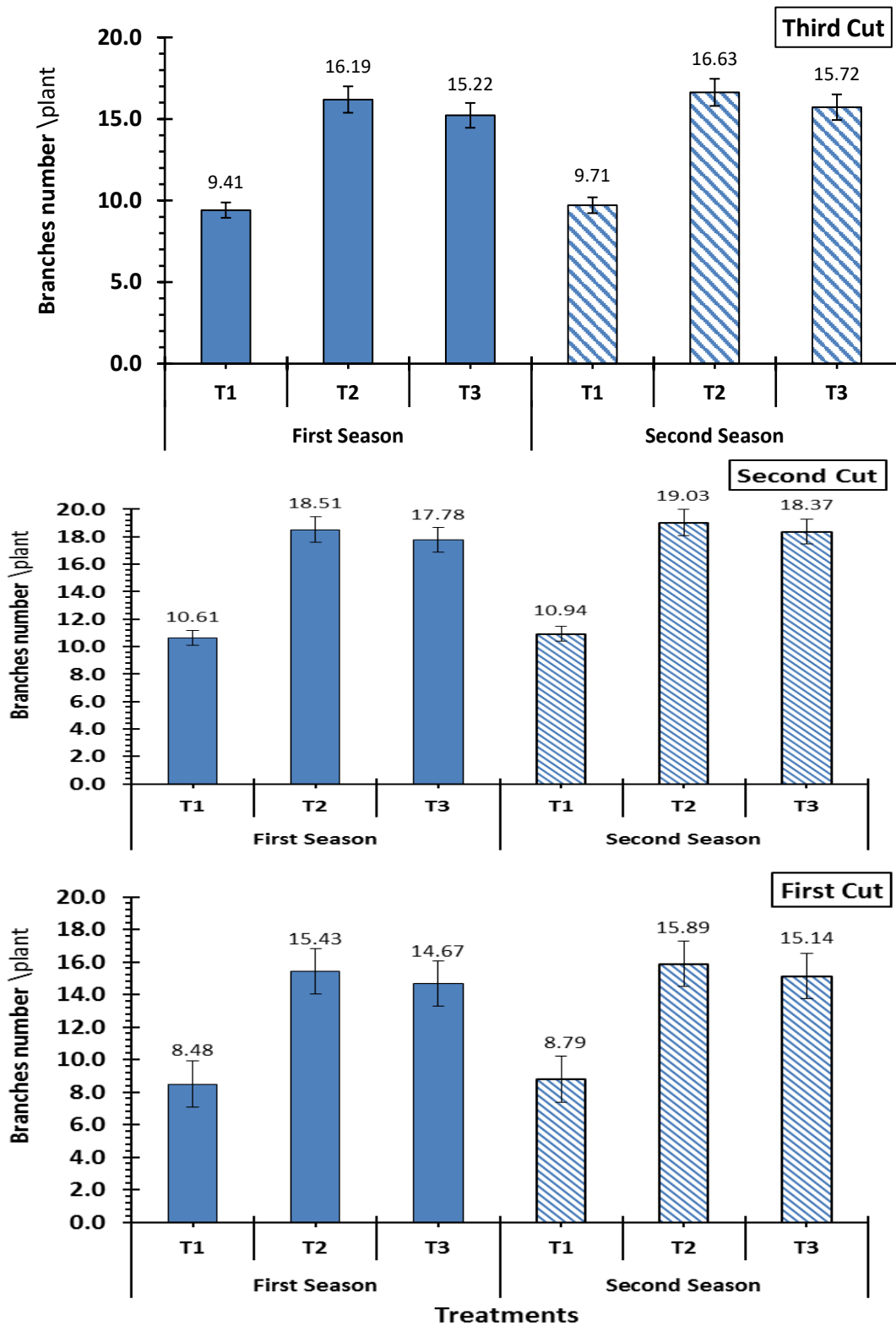


Fig. 2: Effect of combined different P-sources with AMF on branches number of sweet basil during three cutting in both seasons

T₁= (check treatment), T₂=super phosphate + *arbuscular mycorrhizal fungi* (AMF) and T₃= rock phosphate+ *arbuscular mycorrhizal fungi* (AMF).

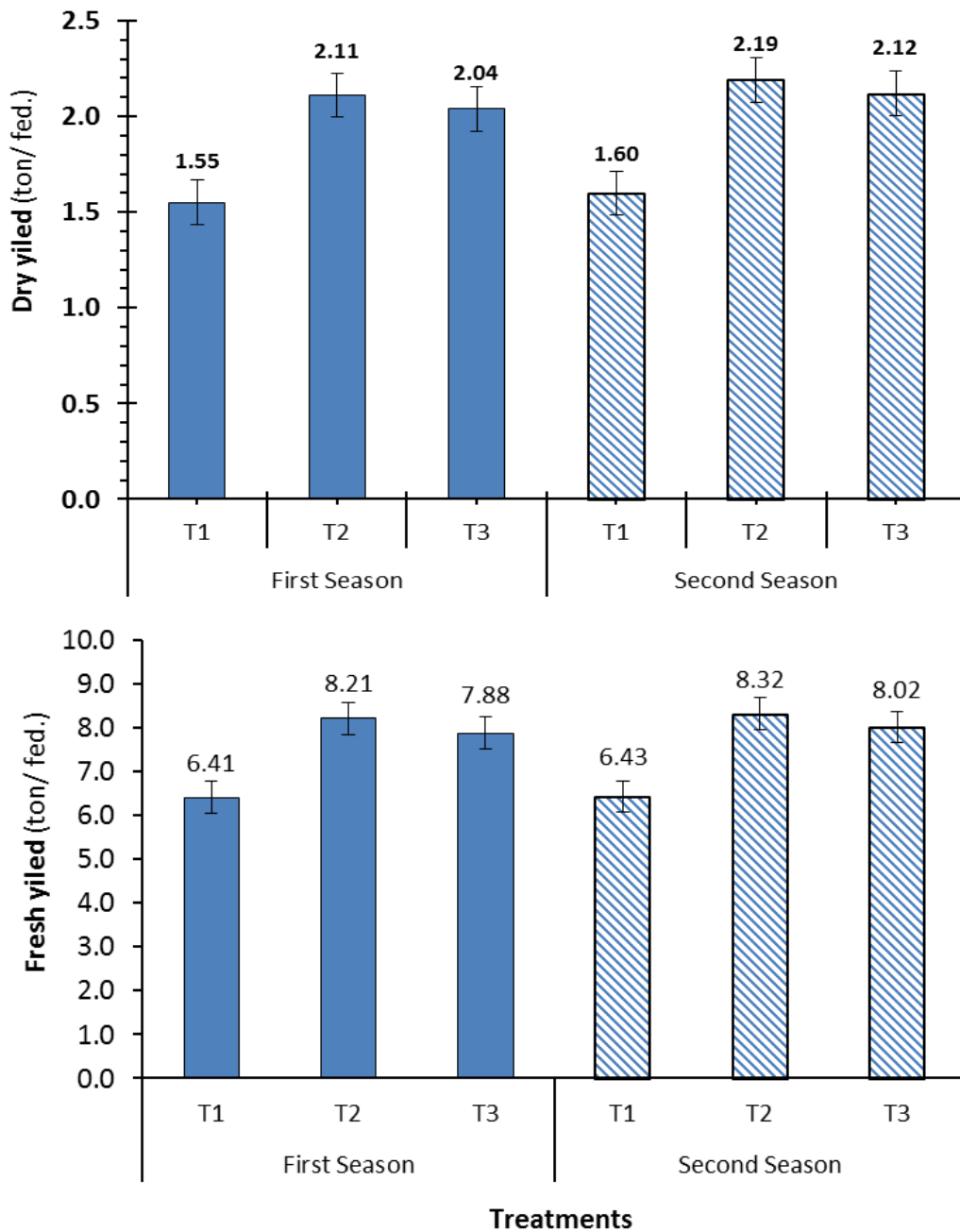


Fig. 3: Effect of combined different P-sources with AMF on total fresh and dry yield of sweet basil during both seasons

T₁= (check treatment), T₂=super phosphate + arbuscular mycorrhizal fungi (AMF) and T₃= rock phosphate+ arbuscular mycorrhizal fungi (AMF).

Table 1: Some physiochemical properties of the experimental site

Property	First season	Second season
pH (1:2.5 suspension)	8.11	8.16
EC _e (dSm ⁻¹)	1.81	1.90
Organic matter (g kg ⁻¹)	10.50	11.90
Sand (%)	20.40	20.40
Silt (%)	44.20	44.20
Clay (%)	35.40	35.40
Texture	Clay loam	Clay loam
CaCO ₃ (%)	2.60	3.21
Available-N (mg kg ⁻¹)	40.64	35.87
Available Olsen-P (mg kg ⁻¹)	5.21	5.39
Available-K (mg kg ⁻¹)	202.00	156.00
CO ₃ ²⁻ + HCO ₃ ⁻ (mg/L)	2.21	2.23
Cl (mg/L)	1.18	1.21
Ca (mg/L)	2.30	2.35
Mg (mg/L)	1.30	1.33
Na (mg/L)	5.18	5.21
K (mg/L)	0.15	0.17

Each value in this table as mean of three replicates, these values for soil past extract

Table 2: Effect of combined different phosphorus sources with AMF on some soil chemical properties after harvesting sweet basil plants

Treatments	EC (1:2.5; dS/m)		pH (1:2.5 Susp.)		OM (g/kg)		Available-P (mg/kg)	
	1 st Sea.	2 nd Sea.	1 st Sea.	2 nd Sea.	1 st Sea.	2 nd Sea.	1 st Sea.	2 nd Sea.
T ₁ (check)	2.10 ^c	2.17 ^c	7.98 ^a	8.00 ^a	13.30 ^b	13.97 ^b	7.75 ^c	8.05 ^c
T ₂	2.75 ^a	2.83 ^a	8.06 ^a	8.12 ^a	14.00 ^b	14.70 ^b	9.51 ^b	9.89 ^b
T ₃	2.20 ^b	2.26 ^b	8.07 ^a	8.11 ^a	18.50 ^a	19.43 ^a	13.14 ^a	13.66 ^a
Mean	2.35	2.42	8.04	8.08	15.27	16.03	10.13	10.53

Means denoted by the same letter indicate insignificant difference according to Duncan's test at $p < 0.05$. AMF = *arbuscular mycorrhizal fungi*, Sea. = Season, T₁ = *arbuscular mycorrhizal fungi* (check treatment), T₂ = super phosphate+AMF and T₃ = rock phosphate+AMF.

Table 3: Effect of combined different P-sources with AMF on N, P, K and oil-contents of sweet basil during three cutting in both seasons

Treatments	N-content (%)		P-content (%)		K-content (%)		Oil-content (%)	
	1 st Sea.	2 nd Sea.	1 st Sea.	2 nd Sea.	1 st Sea.	2 nd Sea.	1 st Sea.	2 nd Sea.
1 st cut								
T ₁ (check)	1.33 ^c	1.37 ^c	0.15 ^c	0.16 ^c	1.20 ^c	1.77 ^c	0.81 ^c	0.87 ^c
T ₂	1.77 ^a	1.82 ^a	0.22 ^a	0.24 ^a	1.67 ^a	1.78 ^a	1.27 ^a	1.35 ^a
T ₃	1.70 ^b	1.75 ^b	0.21 ^b	0.22 ^b	1.59 ^b	1.68 ^b	1.20 ^b	1.26 ^b
Mean	1.60	1.65	0.19	0.21	1.49	1.74	1.09	1.16
2 nd cut								
T ₁ (check)	1.41 ^c	1.46 ^c	0.16 ^c	0.17 ^c	1.35 ^c	1.43 ^b	0.94 ^c	1.00 ^c
T ₂	1.86 ^a	1.91 ^a	0.24 ^a	0.26 ^a	1.78 ^a	1.90 ^a	1.45 ^a	1.56 ^a
T ₃	1.78 ^b	1.84 ^b	0.23 ^b	0.25 ^b	1.72 ^b	1.83 ^a	1.36 ^b	1.44 ^b
Mean	1.68	1.74	0.21	0.23	1.62	1.72	1.25	1.33
3 rd cut								
T ₁ (check)	1.37 ^b	1.46 ^c	0.15 ^c	0.16 ^c	1.27 ^c	1.35 ^b	0.87 ^c	0.95 ^c
T ₂	1.81 ^a	1.92 ^a	0.24 ^a	0.25 ^a	1.72 ^a	1.81 ^a	1.33 ^a	1.46 ^a
T ₃	1.75 ^a	1.85 ^b	0.22 ^b	0.24 ^b	1.64 ^b	1.74 ^a	1.25 ^b	1.37 ^b
Mean	1.64	1.74	0.20	0.22	1.54	1.63	1.15	1.26
Means	1.64	1.71	0.20	0.22	1.55	1.70	1.16	1.25

Means denoted by the same letter indicate insignificant difference according to Duncan's test at $p < 0.05$. AMF = *arbuscular mycorrhizal fungi*, Sea. = season, T₁ = *arbuscular mycorrhizal fungi* (check treatment), T₂ = super phosphate+AMF and T₃ = rock phosphate+AMF.

4. Conclusions

Under the experimental conditions, the combined application of natural materials whether biological agents or raw rock fertilizers demonstrated significant positive impacts on the growth, quality, and yield of sweet basil, alongside improvements in soil health. Specifically, the integration of rock phosphate and superphosphate with *arbuscular mycorrhizal fungi* (AMF) as a bio-fertilizer significantly enhanced vegetative growth, yield, and quality parameters of basil plants. These improvements support the development of sustainable organic farming systems by reducing reliance on synthetic fertilizers, thereby lowering production costs and minimizing environmental risks. Furthermore, the use of AMF can decrease dependency on conventional phosphate fertilizers such as calcium superphosphate by improving fertilizer use efficiency and facilitating the mobilization of insoluble phosphorus from rock phosphate in alkaline soil conditions.

References

- [1] W. Abd El-Aleem. (2022). Study The Effect of Different Phosphorus Fertilization Resources on The Growth and Productivity of German-Chamomile (*Matricaria chamomilla* L.) Plant under Sand Soil Conditions. *Middle East Journal of Agriculture Research*. 11(03): 770-780.
- [2] W.I.M. Toaima, M. Badawy, E.S. Hamed. (2022). Effect of organic fertilization on productivity of some newly introduced basil varieties under Siwa Oasis conditions. *Journal of Applied Biology & Biotechnology*. 10(2): 74-8.
- [3] K. Carović-Stanko, S. Orlić, O. Politeo, F. Strikić, I. Kolak, M. Milos, Z. Satovic. (2010). Composition and antibacterial activities of essential oils of seven *Ocimum* taxa. *Food chemistry*. 119(1): 196-201.
- [4] A. Alhasan, D. Al-Ameri, M. Al-Baldawy, M. Abbas, H. Hasan. (2020). Influence of foliar application of NPK on growth, essential oil and seed yield of basil (*Ocimum basilicum* L. cv Dolly). *Plant Archives*. 20(Special Issue): 288-291.
- [5] A.M. Shehata, A. Ahmed. (2023). Responses of salt-affected French basil plants grown in new reclamation lands to biofertilization and selenium. *SVU-International Journal of Agricultural Sciences*. 5(4): 69-88.
- [6] M. Arora, P. Saxena, M. Abdin, A. Varma. (2020). Interaction between *Piriformospora indica* and *Azotobacter chroococcum* diminish the effect of salt stress in *Artemisia annua* L. by enhancing enzymatic and non-enzymatic antioxidants. *Symbiosis*. 80(1): 61-73.
- [7] A. Avetisyan, A. Markosian, M. Petrosyan, N. Sahakyan, A. Babayan, S. Aloyan, A. Trchounian. (2017). Chemical composition and some biological activities of the essential oils from basil *Ocimum* different cultivars. *BMC complementary and alternative medicine*. 17(1): 1-8.
- [8] G. Kavooosi, Z. Amirghofran. (2017). Chemical composition, radical scavenging and anti-oxidant capacity of *Ocimum basilicum* essential oil. *Journal of Essential oil Research*. 29(2): 189-199.
- [9] D. Spina, C. Barbieri, R. Carbone, M. Hamam, M. D'Amico, G. Di Vita. (2023). Market trends of medicinal and aromatic plants in Italy: future scenarios based on the Delphi method. *Agronomy*. 13(7): 1703.
- [10] J.K. Syers, A. Johnston, D. Curtin. (2008). Efficiency of soil and fertilizer phosphorus use. *FAO Fertilizer and plant nutrition bulletin*. 18(108): 5-50.
- [11] H. El-Sayed, S. Hegab, M. Youssef, A. Abd Al-Majeed. (2021). Responses of maize (*Zea mays* L.) production and soil fertility to application controlled-release N-fertilizers and poultry manure. *Archives of Agriculture Sciences Journal*. 4(3): 187-204.
- [12] F. Hellal, S. El-Sayed, R. Zewainy, A. Amer. (2019). Importance of phosphate rock application for sustaining agricultural production in Egypt. *Bulletin of the National Research Centre*.
- [13] A.M. Ali, S.A. Hegab, A.M. Abd El Gawad, M. Awad. (2022). Integrated effect of filter mud cake combined with chemical and biofertilizers to enhance potato growth and its yield. *Journal of Soil Science and Plant Nutrition*. 1-10.
- [14] D. Cordell, A. Rosemarin, J.J. Schröder, A. Smit. (2011). Towards global phosphorus security: A systems framework for phosphorus recovery and reuse options. *Chemosphere*. 84(6): 747-758.
- [15] J. Shen, L. Yuan, J. Zhang, H. Li, Z. Bai, X. Chen, W. Zhang, F. Zhang. (2011). Phosphorus dynamics: from soil to plant. *Plant physiology*. 156(3): 997-1005.
- [16] M. Merajipoor, M.M. Dehnavi, A. Salehi, A. Yadavi. (2020). Improving grain yield, water and nitrogen use efficiency of *Nigella sativa* with biological and chemical nitrogen under different irrigation regimes. *Scientia Horticulturae*. 260: 108869.
- [17] M. Abd-Elzaher, I. Ibrahim, F. Khalil, W. Mohamed. (2022). Chemical composition and productivity for corn as affected by inorganic, organic nitrogen fertilizers and activators (Humic and Fulvic acid). *Current Chemistry Letters*. 11(2): 207-18.
- [18] A. Rana, M. Joshi, R. Prasanna, Y.S. Shivay, L. Nain. (2012). Biofortification of wheat through inoculation of plant growth promoting rhizobacteria and cyanobacteria. *European Journal of Soil Biology*. 50: 118-126.
- [19] K. Mohammadi, Y. Sohrabi. (2012). Bacterial biofertilizers for sustainable crop production: a review. *ARPJ Agric Biol Sci*. 7(5): 307-316.
- [20] J. Itelima, W. Bang, I. Onyimba, E. Oj. (2018). A review: biofertilizer; a key player in enhancing soil fertility and crop productivity. *J Microbiol Biotechnol Rep*. 2(1): 22-28.
- [21] H.M. Al-Sayed, A.M. Ali, M.A. Mohamed, M.F. Ibrahim. (2022). Combined effect of prickly pear waste biochar and *Azolla* on soil fertility, growth, and yield of Roselle (*Hibiscus sabdariffa* L.) plants. *Journal of Soil Science and Plant Nutrition*. 22(3): 3541-3552.
- [22] H.M.R. Javeed, R. Naeem, M. Ali, R. Qamar, M.A. Sarwar, F. Nawaz, M. Shehzad, A. Farooq, S. Khalid, K. Mubeen. (2022). Coupling biochar with

- microbial inoculants improves maize growth and nutrients acquisition under phosphorous-limited soil. *Acta Physiologiae Plantarum*. 44(11): 110.
- [23] W. Sun, M.H. Shahrajabian. (2023). The application of arbuscular mycorrhizal fungi as microbial biostimulant, sustainable approaches in modern agriculture. *Plants*. 12(17): 3101.
- [24] A. Hodge, K. Storer. (2015). Arbuscular mycorrhiza and nitrogen: implications for individual plants through to ecosystems. *Plant and soil*. 386(1): 1-19.
- [25] H. Zhang, S. Wei, W. Hu, L. Xiao, M. Tang. (2017). Arbuscular mycorrhizal fungus *Rhizophagus irregularis* increased potassium content and expression of genes encoding potassium channels in *Lycium barbarum*. *Frontiers in Plant Science*. 8: 440.
- [26] S. Danish, S. Kiran, S. Fahad, N. Ahmad, M.A. Ali, F.A. Tahir, M.K. Rasheed, K. Shahzad, X. Li, D. Wang. (2019). Alleviation of chromium toxicity in maize by Fe fortification and chromium tolerant ACC deaminase producing plant growth promoting rhizobacteria. *Ecotoxicology and environmental safety*. 185: 109706.
- [27] N. Ahmed, S. Ahsen, M.A. Ali, M.B. Hussain, S.B. Hussain, M.K. Rasheed, B. Butt, I. Irshad, S. Danish. (2020). Rhizobacteria and silicon synergy modulates the growth, nutrition and yield of mungbean under saline soil. *Pak. J. Bot.* 52(1): 9-15.
- [28] M.C. Brundrett, L. Tedersoo. (2018). Evolutionary history of mycorrhizal symbioses and global host plant diversity. *New Phytologist*. 220(4): 1108-1115.
- [29] A.-B.F. Al-Arjani, A. Hashem, E.F. Abd_Allah. (2020). Arbuscular mycorrhizal fungi modulates dynamics tolerance expression to mitigate drought stress in *Ephedra foliata* Boiss. *Saudi journal of biological sciences*. 27(1): 380-394.
- [30] M. Zhang, Z. Shi, S. Zhang, J. Gao. (2022). A database on mycorrhizal traits of chinese medicinal plants. *Frontiers in Plant Science*. 13: 840343.
- [31] A.A.H.A. Latef, A. Hashem, S. Rasool, E.F. Abd_Allah, A. Alqarawi, D. Egamberdieva, S. Jan, N.A. Anjum, P. Ahmad. (2016). Arbuscular mycorrhizal symbiosis and abiotic stress in plants: a review. *Journal of plant biology*. 59(5): 407-426.
- [32] M. Thioub, N. Ewusi-Mensah, J. Sarkodie-Addo, T. Adjei-Gyapong. (2019). Arbuscular mycorrhizal fungi inoculation enhances phosphorus use efficiency and soybean productivity on a Haplic Acrisol. *Soil and Tillage Research*. 192: 174-186.
- [33] A. Israel, J. Langrand, J. Fontaine, A. Lounès-Hadj Sahraoui. (2022). Significance of arbuscular mycorrhizal fungi in mitigating abiotic environmental stress in medicinal and aromatic plants: a review. *Foods*. 11(17): 2591.
- [34] A.S. Pisco, L.A.A. Lopez. (2021). Efecto bioprotector de micorrizas arbusculares en la reducción de roya (*Hemileia vastatrix*) en la región San Martín. *Revista Agrotecnológica Amazónica*. 1(1): 34-44.
- [35] A.L. Page, R.H. Miller, D.R. Keeney. (1982). *Methods of soil analysis. Part 2. Chemical and Microbiological Properties*. 2nd. Ed. Am. Soc. Agron. Inc. Soil Sci. Soc. Am. Inc. Madison. Wisconsin. USA.
- [36] R. Burt. (2004). *Soil Survey Laboratory methods manual. Soil Survey Investigations Report No. 42, Version 4.0. Natural Resources Conservation Service, United States Department of Agriculture*.
- [37] S.R. Olsen, L.E. Sommers. (1982). *Phosphorus methods of soil analysis. In: Chemical and Microbiological Properties*.
- [38] M. Khan, M. Amin. (2019). Macro nutrient status of Sundarbans forest soils in Southern region of Bangladesh. *Bangladesh Journal of Scientific and Industrial Research*. 54(1): 67-72.
- [39] AOAC, *Official methods of analysis of AOAC. International 17th edition. In A Association of Analytical Communities Gaithersburg, MD, US: 2000*.
- [40] R.G.D. Steel, J.H. Torrie. (1960). *Principles and procedures of statistics*.
- [41] H.M. Farrag, A.A.E.M.A. Bakr. (2023). Effect of applying bio-enriched rock phosphate on soil properties and wheat plant growth. *Egyptian Journal of Soil Science*. 63(1): 1-13.
- [42] T. El-Sherbeny, A.M. Mousa, E.-S.R. El-Sayed. (2022). Use of mycorrhizal fungi and phosphorus fertilization to improve the yield of onion (*Allium cepa* L.) plant. *Saudi journal of biological sciences*. 29(1): 331-338.
- [43] F. Balloei, M. Ardakani, F. Rejali, M. Ramzanpoor, G. Alizade, F. Mohebbati In *Effect of Thiobacillus and Mycorrhiza fungi under different levels of sulfur on yield and yield components of soybean*, International Symposium "Root Research and Applications", RootRAP, Boku, Vienna, Austria, 2009; 2009.
- [44] N. Golubkina, S. Zamana, T. Seredin, P. Poluboyarinov, S. Sokolov, H. Baranova, L. Krivenkov, L. Pietrantonio, G. Caruso. (2019). Effect of selenium biofortification and beneficial microorganism inoculation on yield, quality and antioxidant properties of shallot bulbs. *Plants*. 8(4): 102.
- [45] B.H.M. Abadi, H.R. Ganjali, H.R. Mobasser. (2015). Effect of mycorrhiza and phosphorus fertilizer on some characteristics of black cumin.
- [46] V. Parkash, A. Aggarwal. (2009). Diversity of endomycorrhizal fungi and their synergistic effect on the growth of *Acacia catechu* Willd. *Journal of Forest Science*. 55(10): 461-468.
- [47] A. Wahab, M. Muhammad, A. Munir, G. Abdi, W. Zaman, A. Ayaz, C. Khizar, S.P.P. Reddy. (2023). Role of arbuscular mycorrhizal fungi in regulating growth, enhancing productivity, and potentially influencing ecosystems under abiotic and biotic stresses. *Plants*. 12(17): 3102.
- [48] P. Jia, H. Liu, T. Gao, H. Xin. (2013). Glandular trichomes and essential oil of *Thymus quinquecostatus*. *The Scientific World Journal*. 2013(1): 387952.
- [49] R. Rehman, M.A. Hanif, Z. Mushtaq, B. Mochona, X. Qi. (2016). Biosynthetic factories of essential

- oils: The aromatic plants. *Nat. Prod. Chem. Res.* 4(4): 1000227.
- [50] L.A.A. El-Rahman, D.A.S. Ewais, A. Magda. (2019). Effect of different sources of phosphorus and bio fertilizers on yield and seeds quality of soybean. *Menoufia Journal of Soil Science.* 4(1): 15-35.