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Improving Soil Phosphorus Availability and Its Influence on Faba Bean Performance: Exploring Mineral, Bio and Organic Fertilization with Foliar Application of Iron and Zinc

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COLLABORATIVE efforts among researchers and farmers are essential for implementing these solutions effectively and sustainably to address phosphorus availability challenges in Egyptian agriculture. Additionally, ongoing research and innovation in the field of nutrition can lead to the development of novel approaches to further enhance phosphorus availability and optimize nutrient management practices. So, a field trial was conducted for two successive winter seasons, *i.e.* 2020/21 and 2021/2022 following a split-plot experimental design. The main objective was to enhance soil phosphorus availability and improve faba bean growth through bio and organic fertilization, alongside foliar feeding with iron and zinc. The main plot in the experiment involved soil additions to increase P availability in soil, including control (no additions, negative control), calcium superphosphate added at a rate of. 72 kg P_2O_5 per hectare (positive control), compost (7.2 tons per hectare), citric acid (7.2 kg per hectare), phosphorine (at rate of 10 g inoculant per 1.0 kg seeds), and a combined treatment of compost and citric acid (7.2 tons per hectare +7.2 kg per hectare, respectively). The sub-plot includes foliar application of microelements, with options being no application, iron application (2.4 kg per hectare) and zinc application (2.4 kg per hectare). Various parameters, such as nutrient availability (N, P, K, $mgkg^{-1}$) in soil and organic matter (%) were determined at the harvest stage. Additionally, chemical constituents (N, P, K %) in straw and seeds, along with iron and zinc concentrations (mg kg^{-1}) and protein (%) in seeds, were assessed at harvest. Yield-related components, including the number of pods $plant^{-1}$, weight of seed pod^{-1} (g), weight of 100 seed (g), seed yield (ardb fed^{-1}) and straw yield (ton fed^{-1}),were also measured. The results indicated that all soil additions significantly increased soil phosphorus availability as well as other nutrient availability compared to the control treatment, with the combined treatment (compost + citric) showing superior effects on both soil nutrient availability. The impact of foliar applications of iron and zinc on soil properties was not clearly discernible. In terms of plant-related parameters and yield components, the combined treatment (compost + citric) exhibited the highest values, followed by compost, calcium superphosphate, citric acid, phosphorine, and the control treatments, respectively. Regarding foliar application, iron treatment demonstrated the most substantial increase in chemical traits and yield parameters, followed by zinc treatment, while the control treatment realized the lowest values. These findings underscore the potential of specific soil additions and foliar applications in mitigating phosphorus-related challenges and enhancing faba bean growth in alkaline Egyptian soils.

Keywords: Phosphorus, Calcium superphosphate, Citric acid, Phosphorine, Iron, Zinc .

1. Introduction

The agricultural landscape of Egypt is characterized by its alkaline nature, presenting a unique set of challenges for crop production, especially phosphorus, which has significant repercussions on the productivity of Egyptian soils **(El-Ramady *et al.* 2018).** The rapid fixation of phosphorus, particularly when being added in the form of inorganic calcium superphosphate, results in its swift immobilization, rendering it inaccessible to plants **(El-Ramady *et al.* 2019).** Under the conditions of Egyptian soils, in which the soil pH rises to more than 7.5 - 8.2, phosphorus is deposited in the form of tri calcium phosphate Ca $(PO_4)_2$, which is a complex form that is not readily for the plant. This fixation phenomenon poses a formidable hurdle for plant

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nutrition, affecting the growth and yield of essential crops **(Farid *et al.* 2023).**

To overcome phosphorus problem in Egyptian soils, incorporating compost into agricultural practices has become a strategic approach This additive, not only enriches soils with nutrients needed for proper plant growth, but also stimulates the activities of beneficial microorganisms in soil that may further take part in increasing P availability in soil. Overall, compost application improves soil health and promotes plant growth and crop production **(Elshaboury *et al.* 2024).**

Citric acid acts as a beneficial soil amendment for improving phosphorus availability by chelating, solubilizing, and mobilizing the nutrient **(Santos *et al.* 2017).** Its capacity to modify pH and stimulate microbial activity makes it a valuable tool for addressing the phosphorus problem, particularly in alkaline soils, and optimizing conditions for plant growth **(Mihoub *et al.* 2022).** Soil buffering capacity, which refers to the ability of soil to resist changes in pH, plays a significant role in nutrient availability, including phosphorus. Citric acid can indeed act as a beneficial soil amendment for improving phosphorus availability, particularly in alkaline soils where phosphorus tends to become less accessible to plants due to precipitation and fixation **(Zhu *et al.* 2021)**. Citric acid can solubilize insoluble forms of phosphorus by breaking down mineral complexes and releasing bound phosphorus into the soil solution. This process enhances phosphorus availability for plant roots to absorb. Citric acid can mobilize phosphorus within the soil profile, facilitating its movement towards plant roots **(Paul *et al.* 2021).** This helps overcome the limited diffusion of phosphorus in soil, especially in compacted or poorly structured soils. Citric acid can also influence soil pH, albeit temporarily. Its acidic nature can lower soil pH, creating a more favorable environment for phosphorus availability, especially in alkaline soils where phosphorus tends to become less accessible due to precipitation and fixation at higher pH levels. Citric acid can stimulate microbial activity in the soil. Microorganisms play a crucial role in nutrient cycling, including phosphorus mineralization and transformation processes, thereby enhancing phosphorus availability to plants **(Tian *et al.* 2021).**

Biofertilization (Phosphate-Solubilizing Microorganisms) offers a sustainable approach to enhance phosphorus availability. By harnessing the activities of beneficial microorganisms, biofertilization contributes to improve soil fertility and plant nutrition, ultimately support the sustainable cultivation of crops in phosphorus-deficient environments **(Shams El-Deen *et al.* 2020).**

Iron plays a crucial role in plant nutrition, serving as an essential micronutrient that participates in various physiological vital processes for plant growth and development **(Dey *et al.* 2020).** It is also involved in chlorophyll synthesis, the green pigment critical for photosynthesis (**Li *et al.* 2021).** Iron is a cofactor for enzymes which are involved in electron transport, thus contributing to energy production during photosynthesis **(Schmidt *et al.* 2020).** Additionally, iron plays a key role in the reduction of nitrate to ammonia, facilitating nitrogen metabolism in plants **(Murgia *et al.* 2022).** Its presence is integral to the formation of DNA, RNA, and certain proteins, influencing overall plant structure and function. Despite its significance, iron uptake by plants is influenced by soil pH, with higher alkalinity often limiting its availability. As a result, ensuring an adequate supply of iron is imperative for maintaining optimal plant health, photosynthetic activity, and overall crop productivity **(Ye *et al.* 2022).**

Zinc is another crucial micronutrient which is essential for various aspects of plant nutrition, contributing significantly to overall growth and development **(Abd-Elzaher *et al.* 2022).** One of its primary roles is acting as a cofactor for numerous enzymes involved in various metabolic processes, such as DNA synthesis, protein synthesis, and auxin (plant hormone) metabolism. Zinc also plays a pivotal role in promoting root development and nutrient uptake, influencing the plant's ability to absorb water and other essential nutrients from the soil **(Faiyad *et al.* 2023).** Additionally, zinc is instrumental in the formation of chlorophyll, supporting photosynthesis and the production of carbohydrates. Zinc is a key component of certain enzymes involved in chlorophyll synthesis. Specifically, zinc is a structural component of the enzyme chlorophyllase, which is responsible for the final step in chlorophyll biosynthesis. Without adequate zinc, plants may exhibit chlorosis, or yellowing of leaves, due to impaired chlorophyll production. Its involvement in the synthesis of certain proteins enhances plant resistance to environmental stressors, contributing to improved overall resilience **(Al-Murshidi *et al.* 2023).** On the other hand, zinc deficiency can adversely affect plant growth and yield, maintaining an appropriate level of zinc in the soil is essential for ensuring optimal plant nutrition and, consequently, increasing agricultural productivity **(Al-Abassi *et al.* 2023).**

Recognizing the imperative of addressing the phosphorus challenge, this study delves into multifaceted solutions to enhance soil fertility and optimize crop growth in alkaline Egyptian soils. The investigation focuses on the pivotal roles of compost, biofertilization, and citric acid in facilitating phosphorus availability, offering potential remedies to mitigate the fixation issues prevalent in these soils. Moreover, the study aims to improve plant growth performance and crop quality parameters *via* foliar spraying for both iron and zinc. Acknowledging the strategic significance of local faba beans *(Vicia faba* L.), which serve as a staple in Egyptian diets owing to their high nutritional value **(Elsherpiny and Faiyad 2023), the** research aims to tailor interventions that can positively influence the growth and yield of this crucial crop.

By comprehensively examining the impact of various treatments, the study aspires to contribute valuable insights into sustainable agricultural practices that can optimize the cultivation of fava beans, a vital crop for Egypt's food security.

2. Material and Methods

A field trial was conducted over the winter seasons of 2020/21 and 2021/2022 using a split-plot experimental design. The main plots in the experiment involved soil additives, including control (no additions), calcium superphosphate, compost, citric acid, phosphorine, and a combined treatment of compost and citric acid. The sub-plot considered foliar application of microelements, with options being no application, iron application, and zinc application. Fig 1 illustrates the schematic diagram showing the studied treatments.

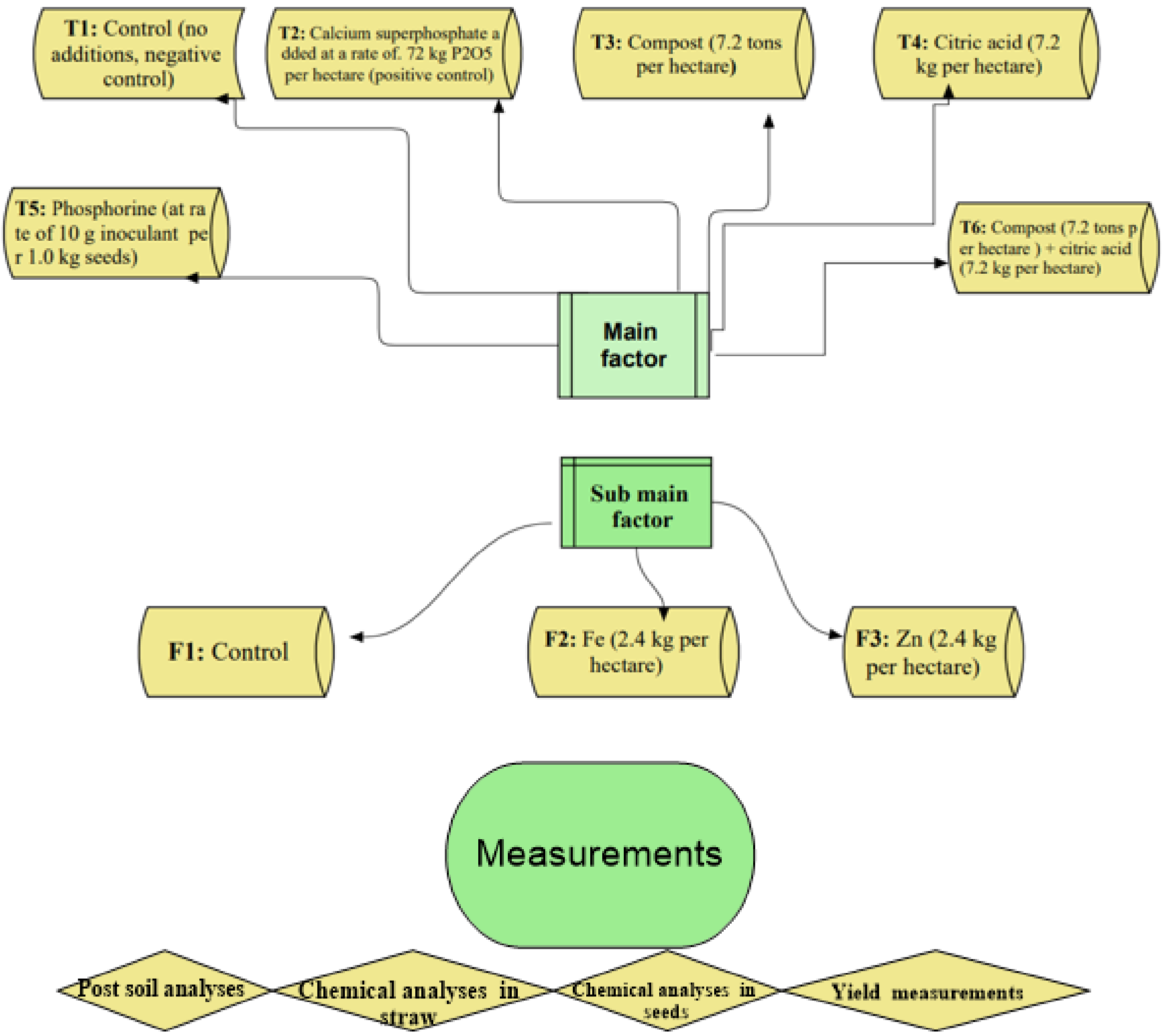

Fig. 1. Schematic diagram showing the studied treatments and measurements.

Experimental site

The research was conducted at the experimental farm of the Agricultural Research Center (ARC) situated in Sakha city, Kafr El-Sheikh governorate, Egypt.

Soil sampling

Table 1 shows the initial soil properties (before sowing), as all analyses were done according to the methodologies of **Tandon (2005).**

Studied substances

Calcium superphosphate (15.5% P_2O_5): It was sourced from Abu Zaabal Fertilizers and Chemicals Company in Egypt. It was added at rate of 72 kg P_2O_5 per hectare during soil tillage.

Compost: A composting process for plant residues (rice and maize stover) was initiated six months before the begining of the field experiment at the experimental site, following the guidelines outlined by **Inckel *et al.* (2005).** To prepare the compost, a space measuring 2.5 x 2.5 m was established atop the field for constructing a pyramid-shaped pile. The initial layer comprised plant waste, followed by the addition of stimulants and moisture. Ten layers were arranged in a pyramid formation before covering the pile with straw. Stirring occurred every two weeks thereafter. The compost traits were presented in Table 2. One month before sowing, compost was incorporated into the soil at a rate of 7.2 tons per hectare.

Biofertilizer: It was sourced from ARC**.** Before the sowing immediately, it was mixed with wet seeds at rate of at rate of 10 g inoculant per 1.0 kg seeds (10 g kg^{-1} seeds).

Citric acid ($C_6H_8O_7$): It was sourced from the Egyptian commercial market (Agro Ferti Company). The anhydrous form has a molar mass of 192.123 g/mol. In terms of appearance, this form typically manifests as white solids. Furthermore, citric acid is generally odorless, which means it lacks a distinct scent. Its purity was 95-98%. It was added at rate of 7.20 kg per hectare before sowing immediately.

Iron and zinc: Fe-EDTA (13 % Fe) and Zn-EDTA (14%Zn) were sourced from Delta Fertilizers and Chemical Industries Company, Talkha District, El-Dakahlia Governorate, Egypt, respectively. They applied as foliar application at rate of 2.4 kg per hectare for each.

Table 1. Properties of the initial soil.

Depth	**Coarse sand,%**	**Fine sand,%**	**Silt,%**	**Clay,%**	**Texture**	**pH**	**EC, dSm^{-1}**
0-20 cm	6.2	14.7	32.5	46.6	**Clayey**	7.97	3.21
20-40 cm	5.9	15.4	33.7	45	**Clayey**	7.93	3.38
Depth	**Ca^{++}**	**Mg^{+}**	**Na^{+}**	**K^{+}**	**CO_3^{--}**	**HCO_3^{-}**	**Cl^{-}**
0-20 cm	8.3	4.1	18.5	1.23	ND	0.32	23.1
20-40 cm	8.1	4.8	19.6	1.38	ND	0.38	24.4
Depth	**Bulk density**	**Hydraulic conductivity**	**FC,%**	**WP,%**	**AW,%**	**OM,%**	
0-20 cm	1.23	0.42	39.2	22.3	16.8	1.27	
20-40 cm	1.26	0.38	39.7	22.7	17.2	1.21	
Depth	**T-P**	**A-Fe**	**A-Zn**	**A-N**	**A-P**	**A-K**	
0-20 cm	80	2.1	0.46	23	4.4	123.7	
20-40 cm	85	1.8	0.41	17.6	4.1	118.7	

Table 2. Properties of the compost.

Seasons	**EC (1:10)**	**pH (1:10)**	**N, %**	**C:N**	**P,%**	**K,%**	**OM,%**	**OC,%**
1st season	3.5	7.9	1.39	16.55	0.39	2.22	41.73	23
2nd season	3.2	7.8	1.35	15.56	0.37	1.95	38	21

Faba bean seeds

Seeds (Giza 716, early cultivar) were obtained from ARC.

Experimental set up

On the first week of December in both investigated seasons, sowing was carried out at a rate of 72 kg per hectare, placing one seed per hill on one side of the ridge, and maintaining a 20 cm spacing between hills.

The nitrogen dose (effective dose), in the form of ammonium sulfate (20.5% N), was applied at a rate of 24 kg N per hectare during planting. Additionally, potassium sulfate (48% K_2O) was administered as a single dose before the second irrigation event, with a rate of 57.6 kg K_2O per hectare.

Adherence to the Ministry of Agriculture and Soil Reclamation (MASR), Egypt, recommendations was maintained for all agricultural practices, irrigation procedures, and weed and disease control, with special attention given to the management of broomrapes (*Orobanche* spp.). Foliar applications were repeated four times throughout the experiment, as the first one was one month after sowing and spaced at two-week intervals between each application (at 30, 44, 58, 72 days from sowing). Each application involved the use of a volume of 1200 L per hectare. Harvesting took place during the first week of April in both seasons.

Measurement traits

During the harvest period, five plants were randomly selected from each replicate for the measurement and determination of the characteristics outlined in Table 3.

Statistical analyses

The analysis of variance (ANOVA) and LSD were calculated *via* CoStat version 6.303 copyrighted (1998-2004**)** using Duncan method **(Gomez and Gomez, 1984).**

Table 3. Methods, formula, and references of measurements.

Measurements	Methods	References
Post soil analyses		
Soil-available nitrogen (NH_4+ NO_3^-), mg kg^{-1}	*Via* Kjeldahl method using K_2SO_4, (1%), devarda alloy andH_3NSO_3, (2%)	**Tandon (2005)**
Soil-available phosphorus, mg kg^{-1}	*Via* Olsen method by spectrophotometer using $NaHCO_3$	
Soil-available potassium, mg kg^{-1}	*Via* flame photometer method using $NH_4CH_3CO_2$	
Organic matter content (O.M,%)	*Via* Walkley and Black method using $K_2Cr_2O_7$, $FeSO_4$, $KMnO_4$ and $H_2C_2O_4.2H_2O$	
Electrical conductivity (EC,dSm^{-1})	*Via* EC meter	
Soil pH	*Via* pH meter	
Chemical analyses either in straw or in seeds		
Digested straw and seed samples	Mixed of $HClO_4$ + H_2SO_4	**Peterburgski (1968)**
Nitrogen in both straw and seeds (%)	Micro-kjeldahl method	**Walinga *et al.* (2013)**
Phosphorus in both straw and seeds (%)	Spectrophotometrically (Olsen)	
Potassium in both straw and seeds (%)	Flame photometer	
Iron in seeds (mg kg^{-1})	Atomic adsorption	
Zinc in seeds (mg kg^{-1})		
Yield and other measurements		
Number of pods $plant^{-1}$, weight of seed pod^{-1} (g), weight of 100 seed (g), seed yield (ardb fed^{-1}) and straw yield (ton fed^{-1})	Manually and visually	----------------
Protein (%)		**A.O.A.C (2000)**

3. Results

Post-harvest soil analyses

Data in Table 4 illustrate the effect of the studied soil amendments and foliar application of Fe and Zn on soil nutrient availability (N, P, K in mg kg^{-1}) and organic matter (%), after the harvest of faba bean during the seasons of 2020/2021 and 2021/2022. Fig 2 shows the effects of the investigated inputs on the mean values of other soil properties such as pH and electrical conductivity (EC, dSm^{-1}) (combined data over both seasons). The impact of foliar applications of iron and zinc on soil properties was not clearly discernible. On the contrary, the results indicated that all soil additions significantly increased the availability of soil nitrogen, phosphorus and potassium as well as organic matter content compared to the control treatment, with the combined treatment (compost + citric) showing superior effects on soil nutrient availability. The compost treatment alone came in the second order followed by phosphorine treatment then citric acid and the last soil amendment in terms of positive effect was calcium superphosphate. The same trend was confirmed in the second season. Regarding pH and EC, the soil amendments slightly affected their values. The combined treatment of compost and citric, followed by compost alone, citric alone and phosphorine led to a slight decrease in pH values compared to other soil amendments and the control treatment. Simultaneously, they contributed to slight increases in EC values.

Table 4. Effect of soil addition of mineral, bio and organic additions as well as foliar application of microelement on soil nutrient availability after harvest of faba bean during seasons of 2020/2021 and 2021/2022.

Treatemnts		N, mg kg^{-1}		P, mg kg^{-1}		K, mg kg^{-1}		OM, %	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Control	Control	18.8	19.2	3.82	3.31	134.2	134.8	1.29	1.28
	Fe	21.4	21.8	2.89	2.54	145.2	145.7	1.28	1.26
	Zn	21.5	22.8	3.01	2.32	150.4	150.5	1.29	1.25
Calcium superphosphate	Control	23.8	24	5.23	5.22	140.13	140.23	1.30	1.29
	Fe	24.2	24.1	3.72	3.89	148.2	148.5	1.29	1.29
	Zn	25.4	25.7	3.91	3.95	152.7	153.05	1.29	1.28
Compost	Control	41.6	42	11.3	11.35	223.1	223.3	1.52	1.51
	Fe	44.1	44.3	9.74	9.79	234.2	234.5	1.5	1.52
	Zn	43.8	43.9	10.12	10.21	238.1	238.4	1.49	1.53
Citric acid	Control	26.4	26.6	7.81	7.85	150.3	150.2	1.32	1.35
	Fe	27.7	27.8	6.67	6.75	157.2	157.6	1.33	1.36
	Zn	27.4	27.2	7.21	7.25	159.2	159.2	1.3	1.33
Phosphorine	Control	38.4	39	8.62	8.73	156.23	156.35	1.38	1.36
	Fe	39.6	39.1	7.42	7.47	162.1	162.4	1.36	1.36
	Zn	40.1	40.6	7.86	7.91	164.2	164.5	1.36	1.35
Compost+ citric acid	Control	42.1	42.4	14.5	15.12	226.4	226.6	1.52	1.50
	Fe	45.4	45.8	9.76	9.81	229.2	229.5	1.51	1.50
	Zn	46.5	46.2	11.2	11.4	231.2	232.0	1.52	1.52

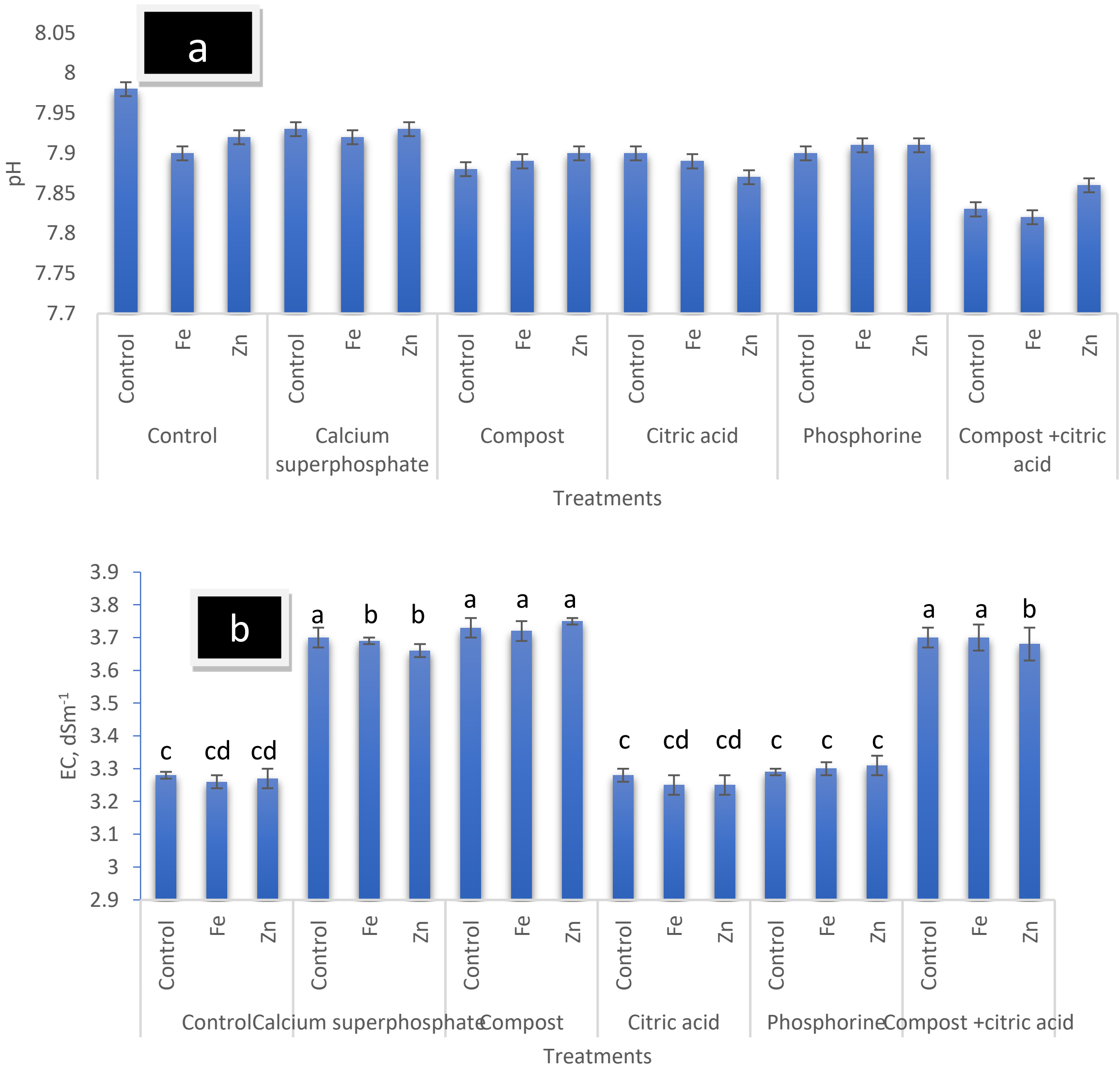

Fig. 2. Effect of soil addition of mineral, bio and organic additions as well as foliar application of microelement on soil pH (a) and electrical conductivity (b) after harvest of faba bean during seasons of 2020/2021 and 2021/2022.

Chemical constituents

Data of Table 5,6,7 illustrate the effect of the studied soil amendments and foliar application on chemical constituents (N, P, K %) in straw and seeds, along with iron and zinc concentrations (mg kg^{-1}) and protein (%) in seeds of faba bean during the seasons of 2020/2021 and 2021/2022. The results indicated that the combined treatment (compost + citric) exhibited the highest values of all aforementioned traits followed by compost, then calcium superphosphate, citric acid, and phosphorine, respectively. All the above treatments exceeded the control one. Regarding foliar application, iron treatment demonstrated the most substantial increase in chemical traits (N,P, K, Fe) in bean straw followed by zinc treatment, while the control treatment exhibited the lowest values. Concerning zinc concentration in seeds, the Zn treatment recorded the highest values followed by Fe treatment and finally control treatment. These trends were consistent along the two studied seasons.

Table 5. Effect of soil addition of mineral, bio and organic additions as well as foliar application of microelement on chemical constituents (N, P, K %) in faba bean straw after 90 days from sowing during seasons of 2020/2021 and 2021/2022.

Treatemnts		N, %		P, %		K, %	
		1st	2nd	1st	2nd	1st	2nd
Main factor							
T_1: Control		1.15f	1.22f	0.07f	0.08e	1.55f	1.57f
T_2: Calcium superphosphate		2.21c	2.32c	0.19c	0.20b	2.66c	2.72c
T_3: Compost		2.34b	2.46b	0.23b	0.24a	3.06b	3.10b
T_4: Citric acid		1.82d	1.90d	0.14d	0.15c	2.38d	2.41d
T_5: Phosphorine		1.47e	1.54e	0.12e	0.13d	1.91e	1.93e
T_6: Compost + citric acid		2.81a	2.95a	0.24a	0.26a	3.19a	3.24a
LSD at 5%		**0.03**	**0.05**	**0.01**	**0.02**	**0.03**	**0.05**
Sub main factor							
F_1:Control		1.78c	1.87c	0.13c	0.14c	2.32c	2.35c
F_2: Iron		2.13a	2.24a	0.20a	0.21a	2.62a	2.66a
F_3: Zic		1.99b	2.09b	0.16b	0.17b	2.44b	2.48b
LSD at 5%		**0.01**	**0.04**	**0.004**	**0.02**	**0.02**	**0.02**
Interaction							
T_1	**F_1**	1.07	1.13	0.04	0.06	1.46	1.48
	F_2	1.17	1.23	0.08	0.09	1.69	1.71
	F_3	1.23	1.29	0.09	0.09	1.51	1.53
T_2	**F_1**	2.02	2.12	0.18	0.19	2.43	2.47
	F_2	2.39	2.50	0.26	0.27	2.93	2.99
	F_3	2.23	2.35	0.13	0.14	2.64	2.70
T_3	**F_1**	2.15	2.25	0.23	0.24	2.97	3.02
	F_2	2.47	2.61	0.26	0.27	3.16	3.21
	F_3	2.40	2.52	0.18	0.20	3.04	3.09
T_4	**F_1**	1.71	1.80	0.13	0.15	2.27	2.31
	F_2	1.94	2.03	0.17	0.18	2.55	2.59
	F_3	1.80	1.89	0.12	0.13	2.32	2.35
T_5	**F_1**	1.34	1.41	0.11	0.13	1.72	1.74
	F_2	1.67	1.75	0.17	0.18	2.04	2.07
	F_3	1.39	1.46	0.07	0.07	1.96	1.99
T_6	**F_1**	2.39	2.51	0.24	0.25	3.06	3.10
	F_2	3.15	3.32	0.28	0.29	3.35	3.39
	F_3	2.88	3.02	0.21	0.23	3.17	3.22
LSD at 5%		**0.03**	**0.11**	**0.01**	**0.04**	**0.06**	**0.06**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 6. Effect of soil addition of mineral, bio and organic additions as well as foliar application of microelement on chemical constituents (N, P, K %) in faba bean seeds at harvest time during seasons of 2020/2021 and 2021/2022.

Treatemnts		N, %		P, %		K, %	
		1st	2nd	1st	2nd	1st	2nd
Main factor							
T_1: Control		2.75f	2.83f	0.12f	0.12f	1.60f	1.63f
T_2: Calcium superphosphate		4.52c	4.66c	0.37c	0.39c	2.97c	3.03c
T_3: Compost		4.83b	4.98b	0.49b	0.51b	3.31b	3.38b
T_4: Citric acid		4.04d	4.18d	0.27d	0.28d	2.54d	2.59d
T_5: Phosphorine		3.64e	3.76e	0.18e	0.19e	2.33e	2.38e
T_6: Compost + citric acid		5.21a	5.39a	0.59a	0.62a	3.73a	3.80a
LSD at 5%		**0.05**	**0.04**	**0.01**	**0.01**	**0.05**	**0.08**
Sub main factor							
F_1:Control		4.00c	4.13c	0.28c	0.29c	2.53c	2.58c
F_2: Iron		4.40a	4.55a	0.39a	0.41a	2.95a	3.01a
F_3: Zic		4.09b	4.23b	0.34b	0.35b	2.76b	2.82b
LSD at 5%		**0.02**	**0.04**	**0.004**	**0.01**	**0.02**	**0.06**
Interaction							
T_1	**F_1**	2.72	2.80	0.07	0.07	1.38	1.41
	F_2	2.93	3.01	0.12	0.13	1.76	1.80
	F_3	2.59	2.67	0.15	0.16	1.66	1.69
T_2	**F_1**	4.17	4.30	0.32	0.34	2.75	2.81
	F_2	4.91	5.07	0.43	0.45	3.26	3.32
	F_3	4.48	4.61	0.35	0.37	2.90	2.96
T_3	**F_1**	4.67	4.82	0.41	0.43	3.00	3.06
	F_2	5.07	5.24	0.59	0.62	3.55	3.63
	F_3	4.75	4.89	0.47	0.49	3.37	3.45
T_4	**F_1**	3.89	4.01	0.21	0.22	2.34	2.38
	F_2	4.27	4.42	0.33	0.35	2.70	2.74
	F_3	3.96	4.10	0.27	0.28	2.60	2.66
T_5	**F_1**	3.47	3.59	0.16	0.17	2.16	2.21
	F_2	3.86	3.98	0.20	0.21	2.47	2.52
	F_3	3.59	3.72	0.18	0.19	2.37	2.42
T_6	**F_1**	5.08	5.23	0.51	0.53	3.55	3.62
	F_2	5.38	5.57	0.67	0.70	3.97	4.04
	F_3	5.19	5.37	0.59	0.62	3.66	3.73
LSD at 5%		**0.05**	**0.11**	**0.01**	**0.03**	**0.04**	**0.14**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 7. Effect of soil addition of mineral, bio and organic additions as well as foliar application of microelement on seeds quality [iron (Fe) and zinc (Zn) concentrations and protein] of faba bean at harvest time during seasons of 2020/2021 and 2021/2022.

Treatemnts		Fe , mg kg^{-1}		Zn, mg kg^{-1}		Protein , %	
		1st	2nd	1st	2nd	1st	2nd
Main factor							
T_1:Control		42.96f	43.88f	13.93f	14.19f	17.17f	17.66f
T_2: Calcium superphosphate		69.96c	71.73c	39.62c	40.44c	28.25c	29.14c
T_3:Compost		73.41b	75.29b	41.37b	42.19b	30.19b	31.15b
T_4: Citric acid		59.68d	60.89d	21.80d	22.25d	25.24d	26.10d
T_5:Phosphorine		55.58e	56.75e	19.07e	19.43e	22.74e	23.51e
T_6:Compost + citric acid		78.52a	80.60a	44.15a	44.99a	32.58a	33.69a
LSD at 5%		**0.78**	**0.17**	**0.11**	**0.40**	**0.32**	**0.26**
Sub main factor							
F_1:Control		58.51c	59.89c	26.02c	26.53c	25.00c	25.78c
F_2: Iron		68.51a	70.10a	29.06b	29.65b	27.51a	28.43a
F_3: Zic		63.03b	64.59b	34.89a	35.57a	25.58b	26.41b
LSD at 5%		**0.73**	**0.21**	**0.16**	**0.30**	**0.13**	**0.27**
Interaction							
T_1	**F_1**	40.13	41.03	10.04	10.24	17.02	17.52
	F_2	46.30	47.20	10.73	10.90	18.29	18.79
	F_3	42.43	43.41	21.02	21.43	16.21	16.67
T_2	**F_1**	64.23	65.81	34.91	35.58	26.08	26.90
	F_2	76.37	78.39	39.00	39.75	30.67	31.71
	F_3	69.27	71.00	44.96	45.99	28.00	28.81
T_3	**F_1**	65.67	67.38	37.13	37.91	29.19	30.10
	F_2	79.60	81.45	41.01	41.87	31.69	32.77
	F_3	74.97	77.04	45.97	46.80	29.69	30.58
T_4	**F_1**	56.00	57.11	18.15	18.60	24.29	25.04
	F_2	62.97	64.33	21.21	21.57	26.69	27.65
	F_3	60.07	61.21	26.06	26.59	24.73	25.60
T_5	**F_1**	51.17	52.20	15.10	15.34	21.69	22.42
	F_2	61.27	62.68	18.98	19.39	24.10	24.88
	F_3	54.30	55.38	23.13	23.57	22.42	23.23
T_6	**F_1**	71.53	73.41	40.12	40.88	31.73	32.71
	F_2	87.47	89.67	44.12	45.07	33.60	34.81
	F_3	76.57	78.73	48.21	49.04	32.42	33.54
LSD at 5%		**1.78**	**0.52**	**0.40**	**0.72**	**0.31**	**0.66**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Yield and its components

Data presented in Table 8 indicate the effect of the studied soil amendments and foliar application on yield-related components, including the number of pods plant^{-1}, weight of seed pod^{-1} (g), weight of 100 seed (g), seed yield (ardb fed^{-1}) and straw yield (ton fed^{-1}) at the harvest stage of faba bean during the seasons of 2020/2021 and 2021/2022. The findings reveal that the combined treatment (compost + citric) demonstrated the highest values, succeeded by compost, calcium superphosphate, citric acid, phosphorine, and the control treatments, in that order. In terms of foliar application, the iron treatment exhibited the most substantial increase in yield parameters, followed by zinc treatment, while the control treatment realized the lowest values. The same trend was found in both seasons.

Table 8. Effect of soil addition of mineral, bio and organic additions as well as foliar application of microelement on faba bean yield at harvest time and its components during seasons of 2020/2021 and 2021/2022.

Treatemnts		Number of pods plant^{-1}		weight of seed pod^{-1} (g)		weight of 100 seed (g)		Seed yield (ardb fed^{-1})		Straw yield (ton fed^{-1})	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Main factor											
T_1:Control		14.65f	15.06f	2.13e	2.23e	82.18f	83.68f	8.42e	8.54d	1.42f	1.49f
T_2: Calcium superphosphate		17.63c	18.25c	4.08c	4.29c	95.82c	97.68c	11.66c	11.89b	2.85c	2.99c
T_3:Compost		18.45b	19.08b	4.25b	4.47b	98.76b	100.94b	11.76b	11.92b	3.03b	3.19b
T_4: Citric acid		16.93d	17.49d	2.56d	2.69d	89.92d	91.73d	11.65c	11.26c	2.51d	2.63d
T_5:Phosphorine		15.67e	16.17e	2.51d	2.63d	84.90e	86.63e	11.11d	11.82b	2.31e	2.42e
T_6:Compost + citric acid		18.81a	19.40a	4.59a	4.82a	111.14a	113.34a	13.14a	13.34a	3.61a	3.79a
LSD at 5%		**0.15**	**0.17**	**0.09**	**0.10**	**0.11**	**0.79**	**0.03**	**0.12**	**0.02**	**0.02**
Sub main factor											
F_1:Control		16.60c	17.12c	3.34a	3.51a	91.14c	92.99c	10.86c	11.02c	2.36c	2.47c
F_2: Iron		17.45a	18.04a	3.37a	3.53a	96.38a	98.28a	11.70a	11.88a	2.88a	3.03a
F_3: Zic		17.02b	17.57b	3.36a	3.53a	93.84b	95.73b	11.31b	11.49b	2.62b	2.75b
LSD at 5%		**0.12**	**0.16**	***NS**	***NS**	**0.11**	**0.93**	**0.02**	**0.11**	**0.01**	**0.03**
Interaction											
T_1	**F_1**	13.94	14.34	1.94	2.04	78.80	80.27	6.68	6.79	0.88	0.93
	F_2	15.20	15.62	2.20	2.31	85.44	87.10	9.71	9.86	1.80	1.89
	F_3	14.80	15.23	2.24	2.35	82.30	83.66	8.86	8.98	1.58	1.66
T_2	**F_1**	17.20	17.75	4.22	4.42	92.23	94.11	11.57	11.78	2.52	2.65
	F_2	18.09	18.75	4.03	4.25	98.95	100.72	11.73	11.94	3.13	3.27
	F_3	17.60	18.24	4.00	4.21	96.27	98.21	11.69	11.94	2.89	3.04
T_3	**F_1**	18.11	18.66	4.23	4.44	96.76	98.83	11.62	11.76	2.78	2.91
	F_2	18.83	19.54	4.28	4.50	101.27	103.38	11.96	12.13	3.22	3.40
	F_3	18.40	19.04	4.25	4.46	98.24	100.61	11.70	11.87	3.09	3.25
T_4	**F_1**	16.60	17.16	2.54	2.67	86.75	88.42	11.46	11.60	2.52	2.64
	F_2	17.33	17.89	2.58	2.69	92.24	94.00	11.91	12.09	2.65	2.79
	F_3	16.85	17.41	2.58	2.71	90.77	92.78	11.59	11.77	2.35	2.47
T_5	**F_1**	15.22	15.72	2.51	2.64	81.27	83.06	10.75	10.89	1.87	1.96
	F_2	16.16	16.69	2.50	2.62	89.14	90.91	11.71	11.86	2.84	2.97
	F_3	15.63	16.10	2.51	2.63	84.30	85.92	10.88	11.02	2.22	2.32
T_6	**F_1**	18.51	19.09	4.60	4.82	111.01	113.24	13.11	13.31	3.57	3.75
	F_2	19.07	19.73	4.60	4.83	111.25	113.59	13.19	13.38	3.66	3.85
	F_3	18.84	19.37	4.57	4.80	111.16	113.19	13.13	13.33	3.60	3.78
LSD at 5%		**0.30**	**0.39**	**0.23**	**0.19**	**0.27**	**2.28**	**0.04**	**0.27**	**0.03**	**0.07**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

*NS= no significant

4. Discussion

The superior effects observed with the combined treatment (compost + citric) can be attributed to synergistic interactions between the organic components of compost and the acidifying properties of citric acid. This combination likely enhanced nutrient release and availability in the soil.

The studied compost may have played a crucial role in enhancing the availability of phosphorus in soil. It was rich in organic matter, and when incorporated into the soil, it may have contributed to increased soil organic carbon **(Elbaalawy *et al.* 2023).** This organic matter served as a substrate for microorganisms that may have played a vital role in breaking down complex compounds, including phosphorus, making it more accessible to faba bean plants. Also, the studied compost may have introduced a diverse array of beneficial microorganisms to the soil (**Elsherpiny *et al.* 2023).** These microorganisms, including bacteria and fungi, that participate in nutrient cycling processes, such as mineralization, and helps in converting organic phosphorus into forms that are readily available for plants **(Hussein *et al.* 2022).** Moreover, the studied compost contained organic acids and compounds that could chelate or bind with phosphorus. This chelation process prevents phosphorus from forming insoluble compounds with minerals in the soil, keeping it in a more soluble and plant-available form **(Elbaalawy *et al.* 2023).**

Compost may have contributed to improved soil structure and water retention (**Elsherpiny *et al.* 2023).** Enhanced soil structure allows better root penetration and exploration, facilitating the uptake of nutrients, including phosphorus, by plant roots and this is shown in the plant's ability to absorb the nutrients. Compost may have enhanced the soil's buffering capacity, helping to maintain a more favorable pH range for phosphorus availability **(El-Ramady *et al.* 2018, 2019; Farid *et al.* 2023; Elshaboury *et al.* 2024).** Citric acid in the combined treatment may have played a role in improving the availability of phosphorus in the soil, as it has the ability to form complexes that chelates phosphorus and keep it in a soluble form for longer periods versus mineral fertilizers **(Santos *et al.* 2017)**. This chelation process involves binding citric acid molecules to phosphorus ions, preventing them from reacting with other elements in the soil to form insoluble compounds. This maintains phosphorus in a more soluble and plant-available form. Citric acid also may have acted as a solubilizing agent, breaking down the complex compounds that immobilize phosphorus in the soil **(Mihoub *et al.* 2022).** By dissolving these compounds, citric acid may have helped release phosphorus, making it more accessible for plant uptake.

Phosphorine treatment, though ranking lower, still contributed positively, indicating the role of phosphorus in soil fertility. Biofertilization plays a crucial role in enhancing the availability of phosphorus in soil, providing a sustainable and environmentally friendly approach to address phosphorus-related challenges **(Shams El-Deen *et al.* 2020)**. Biofertilizers often contain phosphate-solubilizing microorganisms such as bacteria and fungi. These microorganisms produce organic acids, enzymes, and other compounds that help solubilize fixed phosphates in the soil. This enzymatic activity breaks down insoluble phosphorus compounds, converting them into forms that are more easily absorbed by plant roots **(Berde *et al.* 2021)**. Biofertilizers influence the rhizosphere, the soil region surrounding plant roots, by promoting the growth of beneficial microorganisms. This microbial activity can alter the soil environment, creating conditions that favor the release of phosphorus from mineral compounds, enhancing its availability to plants. Some microorganisms in biofertilizers produce enzymes, such as phosphatases, that play a role in breaking down organic phosphorus compounds into forms that plants can absorb **(Li *et al.* 2021)**. This enzymatic activity contributes to the mineralization of organic phosphorus, making it more available for plant uptake. Biofertilizers enhance plant growth and root development. As plants grow more vigorously, they can explore a larger volume of soil, increasing the probability of encountering available phosphorus. The improved root system also allows for better nutrient uptake, including phosphorus **(Najafgholi *et al.* 2023)**.

The observed differences in plant-related parameters and yield components following foliar application of iron, zinc, and the control treatment can be attributed to the essential roles that these micronutrients play in various physiological processes within plants.

Iron is a crucial component of chlorophyll, the pigment responsible for photosynthesis. Adequate iron availability promotes chlorophyll synthesis, leading to improved photosynthetic activity and overall plant health. Iron is involved in electron transport chains, facilitating energy transfer within plant cells. This is vital for metabolic processes and growth **(Dey *et al.* 2020; Schmidt *et al.* 2020; Murgia *et al.* 2022)**.

Zinc is a cofactor for numerous enzymes involved in various biochemical reactions, including those related to photosynthesis, DNA synthesis, and hormone regulation. Zinc plays a role in auxin synthesis, a plant hormone crucial for cell elongation and overall plant growth **(Abd-Elzaher *et al.* 2022; Faiyad *et al.* 2023; Al-Murshidi *et al.* 2023; Al-Abassi *et al.* 2023).**

The control treatment, which typically involves no additional supplementation of micronutrients, may lack optimal levels of essential elements required for various plant functions. In the absence of sufficient iron and zinc, plants may experience limitations in key metabolic processes, leading to reduced growth and lower yield **(Al-Murshidi *et al.* 2023; Al-Abassi *et al.* 2023).**

Therefore, the substantial increase in plant-related parameters and yield components observed with iron foliar application can be attributed to the correction of iron deficiency, resulting in improved photosynthesis and metabolic activities **(Ye *et al.* 2022)**. The positive impact of zinc, though slightly less pronounced, indicates its role in supporting various biochemical processes. Conversely, the control treatment, lacking targeted micronutrient supplementation, resulted in comparatively lower plant performance and yield.

5. Conclusion

Based on the notable effectiveness observed, the utilization of a blend of compost and citric acid is suggested as a promising approach to address phosphorus-related issues in alkaline Egyptian soils. Farmers are advised to integrate this combined treatment into their soil management strategies. Furthermore, considering the significant influence of foliar applications of iron and zinc on faba bean growth, farmers are should encouraged to foliar spraying methods for these nutrients. Generally, the findings of this study contribute valuable insights to the development of sustainable agricultural practices tailored to the unique challenges of alkaline Egyptian soils, ultimately aiming to optimize faba bean cultivation and support food security in the region.

Conflicts of interest

Authors have declared that no competing interests exist.

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5. References

Abd-Elzaher, M. A., El-Desoky, M. A., Khalil, F. A., Eissa, M. A., & Amin, A. E. E. A. (2022). Interactive effects of K-humate, proline and Si and Zn nanoparticles in improving salt tolerance of wheat in arid degraded soils. Egyptian Journal of Soil Science, 62(3), 237-251.

Al-Abassi, A. A., Abrahium, N. S., & Mohammed, H. A. (2023). Effect of Spraying with Zinc and Ascorbic Acid on some Antioxidants of Maize (*Zea mays* L.) Affected by Heat Shock. In IOP Conference Series: Earth and Environmental Science (Vol. 1225, No. 1, p. 012073). IOP Publishing.

Al-Murshidi, A. A. S. J., & Jassim, R. A. H. (2023). Effect of zinc sources and levels on zinc uptake and growth and yield of wheat (*Triticum aestivum* L.). In IOP Conference Series: Earth and Environmental Science (Vol. 1158, No. 2, p. 022014). IOP Publishing.

AOAC,(2000)." Official Methods of Analysis". 18th Ed. Association of Official Analytical Chemists, Inc., Gaithersburg, MD, Method 04.

Berde, C. P., Rawool, P., & Berde, V. B. (2021). Phosphate-solubilizing bacteria: Recent trends and applications in agriculture. *Recent Advancement in Microbial Biotechnology*, 27-47.

Dey, S., Regon, P., Kar, S., & Panda, S. K. (2020). Chelators of iron and their role in plant's iron management. Physiology and Molecular Biology of Plants, 26(8), 1541-1549.

Elbaalawy, A. M., Tantawy, M. F., Abd Elhafez, E., & Nada, W. M. (2023). Sulphur compost properties and its amelioration effect on salt affected soil characteristics and productivity. Egyptian Journal of Soil Science, 63(3), 339-354.

El-Ramady, H., Abowaly, M., Elbehiry, F., Omara, A. E. D., Elsakhawy, T. A., Mohamed, S., ... & Abdalla, Z. F. (2019). Stressful environments and sustainable soil management: A case study of Kafr El-Sheikh, Egypt. Environment, Biodiversity and Soil Security, 3(2019), 193-213.

El-Ramady, H., Alshaal, T., Bakr, N., Elbana, T., Mohamed, E., & Belal, A. A. (Eds.). (2018). The soils of Egypt. Springer.

Elshaboury, H. A. E. F., Ibrahim, N. R., & Elsherpiny, M. A. (2024). Enhancing soybean productivity in saline soil conditions: synergistic effects of organic fertilizer and proline co-application. Egyptian Journal of Soil Science, 64(2).

Elsherpiny, M. A., & Faiyad, R. M. N. (2023). Effect of Titanium as a Stimulant of Atmospheric Nitrogen Fixation on Faba Bean Plants. Egyptian Journal of Soil Science, 63(4), 465-474.

Elsherpiny, M. A., Baddour, A., & Kany, M. (2023). Effect of organic and bio fertilization and magnesium foliar application on soybean production. Egyptian Journal of Soil Science, 63(1), 127-141.

Faiyad, R.M, El-Azeiz, E.H. & Yousif, E.E (2023). Effect of Sulfur, Boron, Zinc and Iron on Canola under Salt Affected Soils. Egyptian Journal of Soil Science, 63(4).

Farid, I. M., El-Shinawy, R., Elhussiny, O., Abbas, H., Abbas, M. H., & Bassouny, M. A. (2023). Phosphorus and micronutrient interactions in soil and their impacts on maize growth. Egyptian Journal of Soil Science, 63(4).

Gomez; K. A and Gomez, A.A (1984). “Statistical Procedures for Agricultural Research”. John Wiley and Sons, Inc., New York.pp:680.

Hussein, M., Ali, M., Abbas, M. H., & Bassouny, M. A. (2022). Composting animal and plant residues for improving the characteristics of a clayey soil and enhancing the productivity of wheat plant grown thereon. Egyptian Journal of Soil Science, 62(3), 195-208.

Inckel, M., de Smet, P., Tersmette, T., & Veldkamp, T. (2005). The preparation and use of compost (Vol. 27). Wageningen, The Netherlands: Agromisa.

Li, J., Cao, X., Jia, X., Liu, L., Cao, H., Qin, W., & Li, M. (2021). Iron deficiency leads to chlorosis through impacting chlorophyll synthesis and nitrogen metabolism in Areca catechu L. *Frontiers in Plant Science*, *12*, 710093.

Li, L., Li, T., Meng, H. S., Hong, J. P., & Xie, Y. (2021). Effects of a phosphorus-dissolving agent on the phosphorus absorption of rape and inorganic phosphorus fractions in reclaimed soil supplemented with phosphorus fertilizers.

Mihoub, A., Amin, A. E. E. A. Z., Motaghian, H. R., Saeed, M. F., & Naeem, A. (2022). Citric acid (CA)–modified biochar improved available phosphorus concentration and its half-life in a P-fertilized calcareous sandy soil. *Journal of Soil Science and Plant Nutrition*, 1-10.

Murgia, I., Marzorati, F., Vigani, G., & Morandini, P. (2022). Plant iron nutrition: the long road from soil to seeds. Journal of Experimental Botany, 73(6), 1809-1824.

Najafgholi, H. M., Hasanvand, E., Pakbaz, S., & Rouhani, N. (2023). Investigating Effective Factors in Improving Plant Growth by Native Phosphate-dissolving Bacteria Isolated from Wheat.

Paul, C. S., Mercl, F., Száková, J., Tejnecký, V., & Tlustoš, P. (2021). The role of low molecular weight organic acids in the release of phosphorus from sewage sludge-based biochar. *All Life*, *14*(1), 599-609.

Peterburgski, A. V. (1968)."Handbook of Agronomic Chemistry". Kolos Puplishing House, Moscow,(in Russian, pp. 29-86).

Santos, S. R., Silva, E. D. B., Alleoni, L. R. F., & Grazziotti, P. H. (2017). Citric acid influence on soil phosphorus availability. Journal of Plant Nutrition, 40(15), 2138-2145.

Schmidt, W., Thomine, S., & Buckhout, T. J. (2020). Iron nutrition and interactions in plants. Frontiers in plant science, 10, 1670.

Shams El-Deen, R. O., El-Azeem, A., Samy, A. M., Abd Elwahab, A. F., & Mabrouk, S. S. (2020). Effects of phosphate solubilizing microorganisms on wheat yield and phosphatase activity. Egyptian Journal of Microbiology, 55(The 14th Conference of Applied Microbiology), 71-86.

Tandon, H. L. S. (2005). Methods of analysis of soils, plants, waters, fertilizers & organic manures. Fertilizer Development and Consultation Organization.

Tian, D., Wang, L., Hu, J., Zhang, L., Zhou, N., Xia, J., ... & Gao, H. (2021). A study of P release from Fe-P and Ca-P via the organic acids secreted by Aspergillus niger. *Journal of Microbiology*, *59*(9), 819-826.

Walinga, I., Van Der Lee, J. J., Houba, V. J., Van Vark, W. and Novozamsky, I. (2013). Plant analysis manual. Springer Science & Business Media.

Ye, J. Y., Tian, W. H., & Jin, C. W. (2022). Nitrogen in plants: From nutrition to the modulation of abiotic stress adaptation. *Stress Biology*, *2*(1), 4.

Zhu, H., Bing, H., Wu, Y., Sun, H., & Zhou, J. (2021). Low molecular weight organic acids regulate soil phosphorus availability in the soils of subalpine forests, eastern Tibetan Plateau. *Catena*, *203*, 105328.