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Response of Soybean to Gypsum and Compost as Diluents of Salt Stress under Using Cobalt and Molybdenum

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SALINE soils are prevalent globally, necessitating effective agricultural practices for optimal productivity. This research was undertaken over two consecutive seasons (2022 and 2023) enhancing soybean productivity in saline soil conditions. Three soil amendment treatments [T_1**:** Without addition (control); T_2**:** Agricultural gypsum (gypsum requirements) at a rate of 3.0 ton fed^{-1}; T_3**:** Compost **(**plant residues**)** at a rate of 3.0 ton fed^{-1}] were studied as the main factor. Four treatments of beneficial elements [F_1**:** without application **(**control); F_2**:** Cobalt in the form of cobalt sulfate solution (36%Co); F_3**:** Molybdenum in the form of ammonium molybdate (48.9%Mo); F_4**:** combined application of Co + Mo] *via* foliar application rate of 8.0 mg beneficial element L^{-1} were evaluated as sub main factor. Growth performance parameters, *e.g.*, plant height, fresh and dry weights of leaves and chlorophyll content, were assessed to gauge the development of soybean plants after 80 days from sowing. Additionally, yield-related parameters, including the number of pods per plant, seed yield, and the content of oil, protein, and carbohydrates in the seeds. Furthermore, soil electrical conductivity (EC) and the availability of soil nutrients (N, P, K) were analyzed at the harvest stage. The addition of compost resulted in the highest values for all growth performance and yield parameters under study, followed by the addition of gypsum and, finally, the control treatment. On the other hand, the combined foliar application of cobalt and molybdenum exhibited the maximum values, with Mo alone, Co alone, and the control treatment following in decreasing order. Overall, the most effective treatment for achieving optimal plant performance and yield was the combined treatment of $T_3 \times F_4$. Additionally, compared to the control treatment, gypsum addition decreased soil electrical conductivity (EC) at the harvest stage. Conversely, compost addition led to an increase. Furthermore, compost contributed to and higher nutrient availability in the soil than gypsum. These findings emphasize the potential of strategic soil management practices to mitigate the impact of salinity on crop performance. Therefore, it is recommended that farmers and agricultural practitioners consider the integration of compost and the combined application of cobalt and molybdenum for sustainable soybean cultivation in saline soils, fostering increased agricultural resilience and productivity.

Keywords: Gypsum requirements, plant residues, cobalt sulfate and ammonium molybdate.

1. Introduction

Saline soils to significantly challenge global agricultural practices, adversely affecting crop growth and productivity due to elevated soluble salt levels **(Shaygan and Baumgartl 2022).** This hampers water uptake and nutrient absorption, diminishing yields and jeopardizing agricultural sustainability **(Elbaalawy *et al.*, 2023).**

Addressing this issue requires innovative soil management, with agricultural gypsum being recognized for mitigating soil salinity. It improves soil structure and permeability, facilitating enhanced water infiltration and mitigating the harmful effects of salt accumulation (**Morsy *et al.*, 2022**). Agricultural gypsum operates through a multifaceted mechanism. Primarily, it enhances soil structure by promoting the aggregation of soil particles, leading to improved water infiltration and drainage. This restructuring mitigates

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the adverse effects of salinity by preventing waterlogging and facilitating the leaching of excess salts from the root zone (**Amer *et al.*, 2023**). Additionally, gypsum exhibits a unique ion exchange capacity, displacing sodium ions and promoting the retention of essential calcium ions in the soil. The calcium, in turn, helps ameliorate soil structure, reducing soil crusting and enhancing plant root development. **(Elsherpiny and Kany, 2023).**

Similarly, compost derived from plant residues has emerged as a promising avenue, enhancing soil structure and providing crucial organic matter for optimal plant growth **(Elsherpiny, 2023).** Compost operates through a diverse mechanism that addresses the challenges by high soil salinity. Firstly, the organic matter in compost enhances soil structure **(Awwad *et al.*, 2022),** promoting better water retention and drainage. This structural improvement reduces the risk of waterlogging and facilitates the leaching of excess salts from the soil profile. Moreover, the microbial activity stimulated by compost contributes to the breakdown of organic materials, releasing compounds that bind with and immobilize sodium ions, thus mitigating sodicity. Additionally, the organic content in compost as a carbon source, fostering the growth of beneficial microorganisms that contribute to overall soil health and nutrient cycling **(Hussein *et al.*, 2022).** As a result, compost application directly reduces salinity-related issues and promotes a sustainable and resilient soil environment conducive to plant growth in salt-affected areas.

Additionally, incorporating beneficial elements like cobalt and molybdenum is acknowledged for its potential in bolstering plant resilience to saline conditions by influencing various physiological processes **(Babenko *et al*., 2015; Baddour *et al.* 2021).** Cobalt is a cofactor for some enzymes involved in various metabolic pathways, including those related to fatty acid and amino acid metabolism. Enzymes containing cobalt are involved in processes like respiration and photosynthesis, which are vital for plant growth and development **(Akeel and Jahan 2020).** Cobalt has been suggested to enhance plant tolerance to various environmental stresses, including salinity. It may play a role in mitigating the adverse effects of salt stress on plant growth.Cobalt contributes to the stability of cell membranes and cell walls, influencing the overall structural integrity of plant cells **(Hu *et al.* 2021).**

Molybdenum is a component of the molybdenum cofactor (MoCo), which is essential for the activity of nitrate reductase and nitrogenase enzymes. Nitrate reductase is involved in the conversion of nitrate to nitrite during nitrogen assimilation in plants **(Babenko *et al*., 2015)**. Molybdenum is a cofactor for other enzymes involved in sulfur metabolism, affecting the synthesis of certain amino acids and proteins. Molybdenum plays a role in the uptake and utilization of iron by plants, which is crucial for various physiological processes, including chlorophyll synthesis. Molybdenum is implicated in osmotic regulation and can influence the plant's ability to cope with osmotic stress, such as that induced by high salinity **(Moussa *et al*. 2022).**

In Egypt, where soybean holds economic importance and nutritional value, optimizing soybean cultivation in saline soils is crucial for sustaining both the agricultural sector and the population's nutritional needs. Soybeans are nutritionally dense, serving as a valuable source of plant-based protein, essential amino acids, polyunsaturated and monounsaturated fats, dietary fiber, vitamins (including B-vitamins and vitamin E), and minerals (such as calcium, iron, magnesium, and zinc). Additionally, soybeans contain unique compounds like isoflavones, recognized for their antioxidant properties and potential health benefits. **(Elsherpiny *et al.*, 2023).**

Against this backdrop, the primary objective of this research is to assess and compare the efficacy of agricultural gypsum, compost, and beneficial elements (cobalt and molybdenum) as interventions to enhance soybean productivity in saline soils. The research aims to elucidate these treatments' individual and combined effects on soybean growth parameters, yield components, and soil characteristics. By investigating the synergistic interactions between these amendments, the research seeks to identify optimal strategies for mitigating the adverse impact of soil salinity on soybean crops. The overarching goal is to provide practical insights and recommendations applicable to farmers and agricultural practitioners, enabling them to improve soybean cultivation under saline conditions. This contributes to the economic sustainability of soybean production in Egypt and addresses nutritional needs in the region.

2. Material and Methods

A field research trial was undertaken over two consecutive seasons (2022 and 2023) to enhance soybean productivity in saline soil conditions at the Tag-Elezz Experimental Farm, Agricultural Research Center (ARC), Egypt. Table 1 highlights the attributes of the experimental soil before the sowing.

Table 1. Characteristics of the initial soil.

Property	Values
pH (suspension 1:2.5)	8.0
EC, dS m^{-1}	4.080
Available N, mg kg^{-1}	42.02
Available P, mg kg^{-1}	10.05
Available K, mg kg^{-1}	230.2
Organic matter, %	1.36
Sand	23.00
Clay	49.00
Silt	28.00
Textural	Clay

Soil samples for experimentation were gathered from 0-25 cm depth. The free capillary attraction method determined the electrical conductivity (EC) in a saturated soil paste extract. Soil pH was assessed in a soil suspension (1:2.5 ratio). Soil-available nitrogen, phosphorus, and potassium were extracted using the Kjeldahl method (with potassium chloride), the Olsen method employing a spectrophotometer (with $SnCl_2$), and the flame photometer method (with ammonium acetate), the organic matter content (O.M) was measured using the Walkley and Black method. All the soil above analyses were conducted following the procedures outlined by **Tandon, (2005).** The particle size distribution and with soil texture identificawas were carried out according to the methods described by **Gee and Bauder (1986).**

The present research trial was conducted using a split-plot design, and three replicates were implemented. Three soil amendment treatments [**T_1:** Without addition (control); **T_2:** Agricultural gypsum (gypsum requirements) at a rate of 3.0 ton fed^{-1}; **T_3:** Compost **(**plant residues**)** at a rate of 3.0 ton fed^{-1}] were studied as the main factor. Four treatments of beneficial elements [**F_1:** without application **(**control); **F_2:** Cobalt in the form of cobalt sulfate solution (36% Co); **F_3:** Molybdenum in the form of ammonium molybdate (48.9% Mo); **F_4:** combined application of Co + Mo] *via* foliar application rate of 8.0 mg beneficial element L^{-1} were evaluated as sub-main factor. Tables 2, 3, and 4 depict various characteristics of compost, agricultural gypsum, and beneficial element salts, respectively. Compost was produced on the experimental site, as the plant residues such as rice straw and soybean stover were used in composting process. Agricultural gypsum was procured from the Egyptian commercial market, with the beneficial elements sourced from Sigma Company.

Table 2. Characteristics of the compost used.

Property (plant residues)	Compost
pH (suspension 1:10)	6.000
EC, dSm^{-1}	4.040
Organic matter, %	31.70
Total C, %	18.40
Total N, %	1.560
C:N ratio	11.80

Table 3. Characteristics of the agricultural gypsum used.

Property ($CaSO_4$. $2H_2O$)	Values
pH (suspension 1: 5)	7.750
Sulfur content , g $100g^{-1}$	17.88
Calcium content, g $100g^{-1}$	22.92
EC, dSm^{-1}	2.500
Purity, %	98.30

The experimental area covered 180 m^2. Seeds "***Glycine max* L. Cv Giza 111**", which obtained from ARS, were sown manually on the 25^{th} of May in both studied seasons at a rate of 35 kg fed^{-1} (2-3 seeds $hill^{-1}$), immediately following inoculation with rhizobium. After 20 days from sowing, the grown plants were thinned to obtain one soybean plant only in each hill. The studied substances (compost and gypsum) were applied according to the above treatments mentioned 40 days before sowing. Both Co and Mo were sprayed following the designated treatments three times (after 35, 50, and 65 days from cultivation) during the experiment with a volume of 400 L fed^{-1}.

A nitrogen dose of 15.0 kg urea fed^{-1} (46% N) was uniformly applied across all plots (as an effective dose). Potassium sulfate (48% K_2O) was introduced in two equals installments at a rate of 50 kg fed^{-1} (half as a basal application and the remaining half two months after sowing). Calcium superphosphate (6.6%P) was administered before ploughing at 150 kg fed^{-1}. Two months ago, the soil received agricultural gypsum and underwent regular irrigation until it reached its saturation limit. Traditional agricultural practices, in line with the recommendations of the Field Crop Research

Institute, ARS, Egypt, were implemented. The harvest process took place 120 days after sowing.

Throughout both seasons, evaluations encompassed plant height (cm) at 80 days from sowing and measurements of leaves fresh and dry weights (g plant^{-1}) at the same stage. Chlorophyll content in fresh weight (SPAD) was determined at 80 days from sowing, following the methodology outlined by **Yan *et al.* (2007).** Leaves' samples underwent digestion using a mixture of $HClO_4$ and H_2SO_4 (1:1), as described by **Walinga *et al.* (2013).** Chemical analysis of leaves, specifically nitrogen (N,%), phosphorus (P,%), and potassium (K,%), was carried out at the 80-day mark post-sowing using the Kjeldahl method, spectrophotometric method, and flame photometer for N, P, and K, respectively, following standard procedures reported by **Walinga *et al.* (2013).** After 80 days from sowing, catalase enzyme (CAT, unit mg^{-1} protein^{-1}), and peroxidase enzyme (POD, unit mg^{-1} protein^{-1}) were quantified in fresh weight following the methods outlined by **Alici and Arabaci, (2016)** using spectrophotometric method. Also, proline and malondialdehyde (MDA) were determined at the same stage in fresh weight. Using the spectrophotometric method, the proline (µg.g^{-1} F.W) was determined as described by **Ábrahám *et al*. (2010).** MDA (µmol.g^{-1} F.W, as an oxidative stress indicator) was determined using the spectrophotometric method described by **Mendes *et al.* (2009)**.

At the harvest stage, yield and its components were measured, including the seeds yield, number yield, number of pods per plant, pod weight per plant and seed weight per plant. Additionally, various biochemical traits in milled grains were estimated. Biochemical traits of seeds, encompassing carbohydrates (%), protein (%), and oil (%) were evaluated based on standard methods outlined in **AOAC (2000).**

Moreover, at the harvest stage, soil electrical conductivity (EC) and the availability of soil nutrients (nitrogen, phosphorus and potassium, mg kg^{-1}) were analyzed, following the procedures previously outlined in the initial soil assessment.

Statistical analyses were conducted using CoStat version 6.303 copyright (1998-2004) as reported by **Gomez and Gomez (1984).** Two-way analysis of variance (ANOVA) and species-wise Duncan's multiple range tests, following the methodology outlined by **Duncan (1995),** were employed to compare the mean values between both seasons.

Table 4. Characteristics of the salts used.

Characteristic	Ammonium Molybdate	Cobalt Sulfate
Chemical Formula	$(NH_4)_6Mo_7O_{24}$	$CoSO_4$
Physical Form	White crystalline powder or colorless crystals	Reddish-brown crystalline powder
Solubility	Highly soluble in water	Soluble in water, forming a pink solution

3. Results

Growth criteria, leaves chemical constituents after 80 days from sowing

Data in Tables 5 and 6 show the effect of agricultural gypsum, compost, cobalt and molybdenum on growth criteria of soybean plants *i.e.*, plant height (cm), fresh and dry weights (g plant^{-1}) (Table 5) as well as leaf chemical constituents *i.e.,* N, P, K (%) and chlorophyll reading (SPAD) after 80 days from sowing.. The data illustrate that the addition of compost resulted in the highest values for all studied growth performance and leaf chemical constituents under study, followed by the addition of agricultural gypsum and finally, the control treatment (without gypsum and compost). On the other hand, the combined foliar application of cobalt and molybdenum exhibited the maximum values, with Mo alone, Co alone, and the control treatment following in decreasing order. Overall, the most effective treatment for achieving optimal plant performance and maximum leaf chemical constituents was the combined treatment of $\mathbf{T_3 \times F_4}$. This consistent trend was observed in both seasons.

Table 5. Effect of the gypsum, compost, cobalt and molybdenum on growth parameters of soybean plants during seasons of 2022 and 2023.

Treatments		Plant height (cm)		Fresh weight (g plant^{-1})		Dry weight	
		1st	2nd	1st	2nd	1st	2nd
Soil addition treatments							
T_1: Without		76.20c	78.55c	52.89c	53.91c	13.56c	13.84c
T_2: Agricultural gypsum		86.02b	88.55b	56.97b	58.18b	14.54b	14.85b
T_3: Compost		91.55a	94.42a	60.68a	61.98a	15.38a	15.71a
LSD 5%		**3.57**	**0.24**	**0.53**	**1.46**	**0.39**	**0.04**
Foliar application treatments							
F_1: Without		82.55c	84.99b	55.33c	56.52d	14.17d	14.43c
F_2: With Mo		83.54bc	86.07ab	56.22c	57.37c	14.36c	14.69bc
F_3: With Co		85.65ab	88.31ab	57.43b	58.59b	14.61b	14.94ab
F_4: With Co+ Mo		86.62a	89.32a	58.40a	59.61a	14.84a	15.14a
LSD 5%		**2.68**	**3.51**	**0.90**	**0.49**	**0.17**	**0.38**
Interaction							
T x F		**LSD 5%**					
		4.12	**4.68**	**1.60**	**1.43**	**0.33**	**0.33**
T_1	**F_1**	73.85e	76.29e	51.04j	52.01j	13.17j	13.40j
	F_2	74.94de	77.17e	51.93j	52.98j	13.37j	13.67j
	F_3	77.58de	79.83e	53.81i	54.82i	13.73i	14.01i
	F_4	78.42d	80.92e	54.76hi	55.81hi	13.98hi	14.26hi
T_2	**F_1**	84.18c	86.47d	55.61gh	56.69gh	14.23gh	14.52gh
	F_2	85.06c	87.62cd	56.51fg	57.80fg	14.44fg	14.78fg
	F_3	86.94bc	89.72bcd	57.37ef	58.61ef	14.62ef	14.97ef
	F_4	87.91bc	90.40bcd	58.39de	59.62de	14.88de	15.14de
T_3	**F_1**	89.63ab	92.21abc	59.33cd	60.85cd	15.10cd	15.38cd
	F_2	90.62ab	93.43ab	60.23bc	61.33bc	15.28bc	15.62bc
	F_3	92.42a	95.38a	61.10ab	62.33ab	15.47ab	15.83ab
	F_4	93.52a	96.64a	62.07a	63.42a	15.67a	16.00a

This means that a column followed by a different letter (s) is statistically different at a 0.05 level.

Oxidative stress indicators

Table 7 illustrates the oxidative stress indicators in leaves of soybean plants after 80 days from sowing as affected by gypsum, compost, cobalt and molybdenum during the seasons of 2022 and 2023. Regarding antioxidant enzymes such as peroxidase enzyme (POD, unit mg^{-1} protein^{-1}) and catalase enzyme (CAT, unit mg^{-1} protein^{-1}), the same Table shows that the addition of compost resulted in the highest values followed by the addition of agricultural gypsum and finally, the control treatment (without gypsum and compost). On the other hand, the combined foliar application of cobalt and molybdenum exhibited the maximum values followed by Mo alone, then Co alone and lately, the control treatment. Also, the same Table illustrates that the combined treatment of **$T_3 \times F_4$** realized the highest values. This consistent trend was observed in both seasons. On the contrary, both proline (µg.g^{-1} F.W) and MDA (µmol.g^{-1}) took an adverse trend. Their highest values were realized with control treatments (without any studied substances), while adding either compost or gypsum led to a decline in their values. Also, the foliar application of Co and Mo, either in single or in combination, led to a decline in their values. Similar trends were observed in both seasons under investigation**.**

Table 6. Effect of the gypsum, compost, cobalt and molybdenum on chemical constituents and chlorophyll content of soybean plants during seasons of 2022 and 2023.

Treatments		Leaves nitrogen		Leaves phosphorus (%)		Leaves potassium		Chlorophyll (SDAP, value)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Soil addition treatments									
T_1: Without		3.48c	3.65c	0.342c	0.357c	2.17c	2.28c	41.01c	41.53c
T_2: Agricultural gypsum		3.85b	4.04b	0.383b	0.399b	2.75b	2.89b	45.28b	45.85b
T_3: Compost		4.42a	4.64a	0.413a	0.429a	2.98a	3.13a	46.60a	47.15a
LSD 5%		**0.04**	**0.07**	**0.009**	**0.009**	**0.03**	**0.06**	**0.71**	**0.02**
Foliar application treatments									
F_1: Without		3.79d	3.98d	0.371d	0.386d	2.56d	2.69c	43.78c	44.32c
F_2: With Mo		3.85c	4.05c	0.377c	0.394c	2.61c	2.74bc	44.14bc	44.73b
F_3: With Co		3.97b	4.16b	0.381b	0.396b	2.66b	2.78ab	44.47ab	45.01b
F_4: With Co+ Mo		4.05a	4.25a	0.388a	0.404a	2.71a	2.85a	44.79a	45.33a
LSD 5%		**0.05**	**0.03**	**0.005**	**0.004**	**0.05**	**0.09**	**0.36**	**0.30**
Interaction									
T x F		**LSD 5%**							
		0.10	**0.09**	**0.008**	**0.010**	**0.07**	**0.17**	**1.05**	**0.71**
T_1	**F_1**	3.35h	3.53h	0.333h	0.347g	2.08g	2.19e	40.46g	40.94j
	F_2	3.42h	3.59h	0.340gh	0.355fg	2.13g	2.23de	40.81fg	41.29i
	F_3	3.55g	3.72g	0.344fg	0.359ef	2.20f	2.31de	41.19fg	41.76h
	F_4	3.59g	3.76g	0.351f	0.366e	2.26f	2.37d	41.57f	42.14g
T_2	**F_1**	3.69f	3.88f	0.374e	0.389d	2.69e	2.82c	44.79e	45.38f
	F_2	3.77f	3.97f	0.381de	0.399c	2.73de	2.87c	45.12de	45.73e
	F_3	3.91e	4.09e	0.385cd	0.401c	2.76d	2.89c	45.47cde	46.02de
	F_4	4.03d	4.24d	0.391c	0.407c	2.83c	2.99bc	45.73b-e	46.29d
T_3	**F_1**	4.32c	4.54c	0.406b	0.422b	2.91b	3.06ab	46.11a-d	46.63c
	F_2	4.37bc	4.59bc	0.411b	0.427b	2.97ab	3.11ab	46.49abc	47.18b
	F_3	4.46ab	4.67b	0.414ab	0.430ab	3.01a	3.15ab	46.74ab	47.27ab
	F_4	4.52a	4.76a	0.421a	0.438a	3.03a	3.20a	47.06a	47.54a

This means that within a column followed by a different letter (s) is statistically different at a 0.05 level.

Yield and its components

Tables 8 and 9 point out the effect of agricultural gypsum, compost, cobalt, and molybdenum on soybean quantitative and qualitative yield attributes like seeds yield (ton fed^{-1}), No. of pods $plant^{-1}$, pods weight (g $plant^{-1}$), seeds weight (g $plant^{-1}$) (Table 8) and seeds biochemical traits such as carbohydrates, protein and oil (%) (Table 9) after harvesting.

Regarding the soil addition treatments, the order of effectiveness, from most to least, was **T_3** (compost) >**T_2** (gypsum) >**T_1** (control). In other words, the compost treatment **(T_3)** exhibited the highest increases in all parameter's, indicating soybean quantitative and qualitative yield. Following in the second position was the gypsum treatment **(T_2),** and the control treatment **(T_1)** occupied the last position regarding observed effects.

Table 7. Effect of the gypsum, compost, cobalt, and molybdenum on oxidative stress indicators in leaves of soybean plants during seasons of 2022 and 2023.

Treatments		Peroxidase (POX) (unit mg^{-1} protein^{-1})		Catalase (CAT) (unit mg^{-1} protein^{-1})		Proline (µg.g^{-1} F.W)		MDA (µmol.g^{-1} F.W)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Soil addition treatments									
T$_1$: Without		1.46c	1.52c	67.17c	67.95c	8.35a	8.51a	12.24a	12.62a
T$_2$: Agricultural gypsum		1.96b	2.04b	72.56b	73.43b	8.03b	8.18b	11.00b	11.33b
T$_3$: Compost		2.56a	2.67a	77.97a	79.27a	7.58c	7.73c	9.78c	10.08c
LSD 5%		**0.05**	**0.04**	**0.20**	**1.07**	**0.08**	**0.15**	**0.07**	**0.25**
Foliar application treatments									
F$_1$: Without		1.85d	1.92d	71.18d	72.06c	8.10a	8.25a	11.52a	11.86a
F$_2$: With Mo		1.93c	2.01c	72.13c	73.10bc	8.03ab	8.18a	11.18ab	11.52b
F$_3$: With Co		2.05b	2.14b	73.03b	74.07ab	7.94ab	8.09b	10.78bc	11.12c
F$_4$: With Co+ Mo		2.15a	2.24a	73.92a	74.97a	7.88b	8.05b	10.55c	10.87d
LSD 5%		**0.02**	**0.01**	**0.21**	**1.04**	**0.17**	**0.05**	**0.45**	**0.11**
Interaction									
T x F		**LSD 5%**							
		0.04	**0.04**	**0.67**	**1.26**	**0.16**	**0.24**	**0.61**	**0.31**
T$_1$	**F$_1$**	1.33l	1.38l	65.75l	66.47i	8.44a	8.62a	12.63a	13.02a
	F$_2$	1.42k	1.47k	66.71k	67.70hi	8.36ab	8.50ab	12.38ab	12.77ab
	F$_3$	1.50j	1.57j	67.61j	68.36gh	8.32ab	8.48ab	12.10ab	12.49bc
	F$_4$	1.60i	1.66i	68.63i	69.27g	8.26bc	8.43abc	11.86bc	12.20cd
T$_2$	**F$_1$**	1.78h	1.85h	71.19h	72.18f	8.14cd	8.28bcd	11.64cd	11.97d
	F$_2$	1.87g	1.94g	72.18g	72.82ef	8.06de	8.23cd	11.07de	11.43e
	F$_3$	2.06f	2.14f	73.06f	73.88de	7.99de	8.15d	10.78ef	11.10f
	F$_4$	2.15e	2.23e	73.81e	74.84d	7.92e	8.08de	10.51ef	10.81fg
T$_3$	**F$_1$**	2.43d	2.53d	76.61d	77.52c	7.71f	7.85ef	10.28fg	10.58gh
	F$_2$	2.52c	2.62c	77.52c	78.77bc	7.65fg	7.80f	10.08g	10.36h
	F$_3$	2.61b	2.72b	78.43b	79.97ab	7.49gh	7.64f	9.46h	9.77i
	F$_4$	2.70a	2.82a	79.33a	80.81a	7.45h	7.63f	9.28h	9.60i

This means that a column followed by a different letter (s) are statistically different at a 0.05 level.

Concerning the foliar application treatments, both Mo and Co, alone or in combination, significantly increased the values of soybean quantitative and qualitative yield attributes like seeds yield (ton fed^{-1}), No. of pods plant^{-1}, pods weight (g plant^{-1}), seeds weight (g plant^{-1}) (Table 8) and seeds biochemical traits such as carbohydrates, protein and oil,(%) (Table 9) after harvesting compared to the corresponding plants grown without both Mo and Co **(F$_1$)**. The combined foliar application of cobalt and molybdenum (**F$_4$**) was the superior treatment for obtaining the maximum values followed by the treatment of Co alone **(F$_3$)** Mo alone **(F$_2$)** and lately control treatment **(F$_1$)**.

Hence, it can be noticed that the combined treatment involving compost, cobalt (Co), and molybdenum (Mo) (**T$_3$ × F$_4$**) proved to be the most effective in optimizing soybean productivity. This same trend persisted in both seasons**.**

Post-harvest soil analyses

Table 10 illustrates the impact of agricultural gypsum, compost, cobalt, and molybdenum on soil electrical conductivity (EC, dSm^{-1}), as well as the availability of soil nutrients, including nitrogen (N), phosphorus (P), and potassium (K) ($mg\ kg^{-1}$), at the harvest stage. Also, Figs 1 and 2 show the individual effect of the studied treatments on the EC values at harvest stage.

The findings indicate that the soil additions of both compost and gypsum significantly impacted all the previously mentioned soil traits at the harvest stage. Conversely, all foliar treatments (both Mo and Co, alone or in combination) demonstrated a non-significant effect on the studied soil properties at the harvest stage.

Compared to the control treatment, gypsum addition decreased soil electrical conductivity (EC) at the harvest stage. Conversely, compost addition led to an increase. Furthermore, compost contributed to higher nutrient availability in the soil than gypsum.

Under control treatment, it is observed that the available soil nitrogen at the harvest stage exceeded the initial soil content. This could be attributed to the utilization of the rhizobium inoculant before sowing, immediately impacting the nitrogen levels in the soil. The same trend was found for both studied seasons.

Table 8. Effect of the gypsum, compost, cobalt, and molybdenum on yield of soybean plants and its components during seasons of 2022and 2023.

Treatments		Seed yield ($kg\ fed^{-1}$)		No. of pods $plant^{-1}$		Pods weight ($g\ plant^{-1}$)		Seeds weight ($g\ plant^{-1}$)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Soil addition treatments									
T_1: Without		1232.75c	1252.58c	53.50c	56.42c	43.56c	45.74c	23.67c	24.21c
T_2: Agricultural gypsum		1479.08b	1504.08b	71.25b	73.50b	49.91b	52.46b	28.58b	29.19b
T_3: Compost		1709.67a	1734.25a	84.42a	88.67a	59.26a	62.13a	31.58a	32.21a
LSD 5%		**38.02**	**33.98**	**1.28**	**1.24**	**0.57**	**0.86**	**0.28**	**0.30**
Foliar application treatments									
F_1: Without		1391.56d	1415.11d	65.33b	67.67b	49.33d	51.64d	27.24d	27.82c
F_2: With Mo		1448.56c	1472.33c	67.89b	70.89b	50.43c	53.04c	72.75c	28.33b
F_3: With Co		1499.89b	1521.67b	71.44a	74.78a	51.44b	54.05b	28.18b	28.83a
F_4: With Co+ Mo		1555.33a	1578.78a	74.22a	78.11a	52.44a	55.03a	28.59a	29.16a
LSD 5%		**18.78**	**48.19**	**3.28**	**3.43**	**0.62**	**0.72**	**0.38**	**0.50**
Interaction									
T x F		**LSD 5%**							
		34.91	**90.19**	**6.18**	**6.15**	**1.25**	**0.88**	**0.44**	**0.73**
T_1	**F_1**	1146.33l	1164.67k	48.00h	50.00j	41.94i	43.98k	22.96i	23.54i
	F_2	1204.67k	1223.67jk	50.67gh	53.67ij	43.05hi	45.13j	23.50h	24.01hi
	F_3	1261.00j	1281.00ij	55.00fg	59.00hi	44.12gh	46.40i	23.94g	24.52gh
	F_4	1319.00i	1341.00hi	60.33f	63.00gh	45.11g	47.45h	24.28g	24.75g
T_2	**F_1**	1395.67h	1421.67gh	67.33e	68.33fg	48.34f	50.60g	27.86f	28.41f
	F_2	1452.00g	1485.00fg	69.00e	71.00ef	49.43ef	52.14f	28.35e	28.97ef
	F_3	1505.67f	1526.00ef	73.33de	75.33de	50.48de	53.06e	28.78e	29.45de
	F_4	1563.00e	1583.67de	75.33cd	79.33cd	51.39d	54.02d	29.32d	29.93d
T_3	**F_1**	1632.67d	1659.00cd	80.67bc	84.67bc	57.71c	60.35c	30.91c	31.51c
	F_2	1689.00c	1708.33bc	84.00ab	88.00ab	58.80bc	61.85b	31.40b	32.00bc
	F_3	1733.00b	1758.00ab	86.00ab	90.00ab	59.72ab	62.71b	31.83ab	32.54ab
	F_4	1784.00a	1811.67a	87.00a	92.00a	60.82a	63.61a	32.18a	32.79a

This means that a column followed by a different letter (s) is statistically different at a 0.05 level.

Table 9. Effect of the gypsum, compost, cobalt, and molybdenum on seeds biochemical traits of soybean plants during seasons of 2022and 2023.

Treatments		Protein 1st	Protein 2nd	Carbohydrates (%) 1st	Carbohydrates (%) 2nd	Oil 1st	Oil 2nd
Soil addition treatments							
T_1: Without		27.25c	27.62c	21.37c	22.43c	20.75c	21.21c
T_2: Agricultural gypsum		30.28b	30.71b	22.81b	23.97b	22.79b	23.28b
T_3: Compost		32.59a	33.08a	24.20a	25.38a	24.07a	24.56a
LSD 5%		**0.77**	**0.68**	**0.23**	**0.59**	**0.49**	**0.58**
Foliar application treatments							
F_1: Without		29.55d	30.45d	22.23c	23.28c	22.22b	22.69c
F_2: With Mo		29.94c	30.87c	22.63b	23.79b	22.43ab	22.90b
F_3: With Co		30.20b	31.11b	22.97ab	24.17ab	22.63ab	23.17a
F_4: With Co+ Mo		30.47a	31.36a	23.33a	24.48a	22.87a	23.29a
LSD 5%		**0.25**	**0.24**	**0.64**	**0.44**	**0.48**	**0.19**
Interaction							
T x F		**LSD 5%**					
		0.73	**1.85**	**0.37**	**0.45**	**0.38**	**0.57**
T_1	**F_1**	26.73f	27.54f	20.80g	21.79h	20.41i	20.85e
	F_2	27.14ef	27.97ef	21.17g	22.18h	20.64hi	21.07de
	F_3	27.43ef	28.26ef	21.58f	22.70g	20.84gh	21.41de
	F_4	27.69e	28.54e	21.95ef	23.06fg	21.11g	21.49d
T_2	**F_1**	29.77d	30.67d	22.26e	23.32f	22.47f	22.95c
	F_2	30.19cd	31.15cd	22.68d	23.91e	22.68ef	23.19bc
	F_3	30.45cd	31.41cd	22.96d	24.18de	22.89de	23.43bc
	F_4	30.70c	31.63c	23.33c	24.48cd	23.11d	23.53b
T_3	**F_1**	32.16b	33.14b	23.63c	24.74c	23.77c	24.29a
	F_2	32.48ab	33.50ab	24.06b	25.28b	23.97bc	24.44a
	F_3	32.70ab	33.67ab	24.38ab	25.62ab	24.15ab	24.67a
	F_4	33.02a	33.92a	24.72a	25.89a	24.38a	24.84a

This means that a column followed by a different letter (s) is statistically different at a 0.05 level.

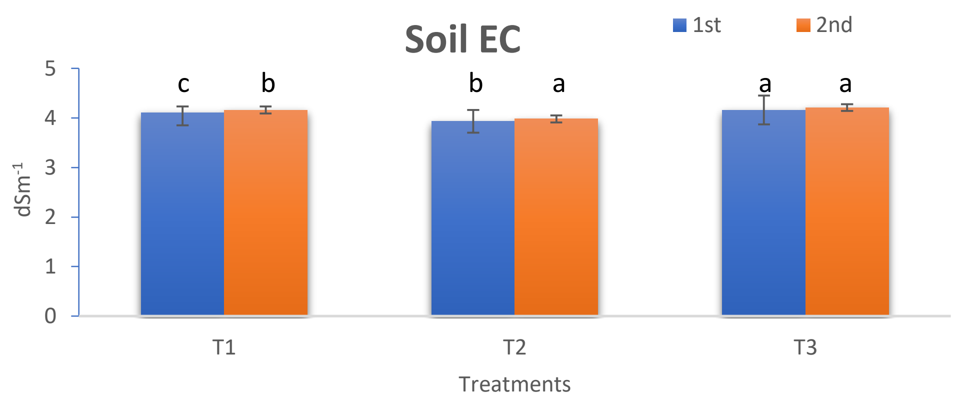

Fig. 1. Effect of the gypsum, compost on soil EC value after harvesting soybean plants during seasons of 2022 and 2023.

T_1: Without addition (control); **T_2:** Agricultural gypsum (gypsum requirements) at a rate of 3.0 ton fed^{-1}; **T_3:** Compost **(**plant residues**)** at a rate of 3.0 ton fed^{-1}

Table 10. Effect of the gypsum, compost, cobalt and molybdenum on some soil properties after harvesting soybean plants during seasons of 2022 and 2023.

Treatments		Soil EC (dSm^{-1})		Soil available nitrogen		Soil available phosphorus		Soil available potassium	
				(mg kg^{-1})					
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Soil addition treatments									
T_1: Without		4.11c	4.16b	42.89c	43.47c	10.26c	10.70c	229.04c	231.75c
T_2: Agricultural gypsum		3.93b	3.98a	46.15b	46.74b	10.53b	10.97b	236.60b	239.32b
T_3: Compost		4.16a	4.21a	49.07a	49.71a	11.01a	11.43a	244.56a	248.46a
LSD 5%		**0.01**	**0.09**	**1.01**	**0.75**	**0.11**	**0.10**	**3.72**	**0.60**
Foliar application treatments									
F_1: Without		4.08a	4.12a	46.45a	46.82a	10.71a	11.14a	239.30a	241.61a
F_2: With Mo		4.08a	4.15a	49.22a	49.47a	11.06ab	11.26ab	245.42a	249.29a
F_3: With Co		4.07a	4.12a	45.86a	46.91a	10.56bc	10.98ab	235.71b	238.21a
F_4: With Co+ Mo		4.07a	4.10a	45.59a	46.19b	10.48c	11.08b	234.12b	241.27a
LSD 5%		***N.S**	***N.S**	***N.S**	**0.37**	**0.13**	**0.19**	**1.96**	***N.S**
Interaction									
T x F		LSD 5%							
		0.03	**0.10**	**0.78**	**1.09**	**0.26**	**0.29**	**5.64**	**5.45**
T_1	**F_1**	4.12c	4.17ab	43.17e	43.67c	10.34efg	10.76efg	230.84fgh	233.58efg
	F_2	4.08d	4.15ab	43.09e	43.45c	10.27fg	10.72fg	229.72fgh	229.45g
	F_3	4.11cd	4.13b	42.81e	43.54c	10.24fg	10.62fg	228.44gh	230.94fg
	F_4	4.13bc	4.17ab	42.50e	43.21c	10.20g	10.68g	227.18h	233.04efg
T_2	**F_1**	3.96e	3.97c	46.55c	46.57b	10.63cd	11.05cde	240.10bcd	243.07bc
	F_2	3.92fg	4.01c	46.44cd	47.00b	10.59cde	10.83def	238.29cde	236.15def
	F_3	3.95ef	4.00c	45.94cd	47.21b	10.48def	10.91d-g	235.15def	237.45de
	F_4	3.91g	3.95c	45.68d	46.18b	10.40d-g	11.10def	232.87efg	240.62cd
T_3	**F_1**	4.17a	4.21ab	49.62a	50.21a	11.17a	11.61a	246.97a	248.18ab
	F_2	4.13bc	4.24a	49.22ab	49.47a	11.06ab	11.26ab	245.42ab	249.29a
	F_3	4.16ab	4.22ab	48.84b	49.98a	10.95ab	11.39ab	243.53abc	246.23ab
	F_4	4.18a	4.17ab	48.58b	49.18a	10.83bc	11.47bc	242.32abc	250.14a

This means that a column followed by a different letter (s) is statistically different at a 0.05 level.
*N.S= non-significant

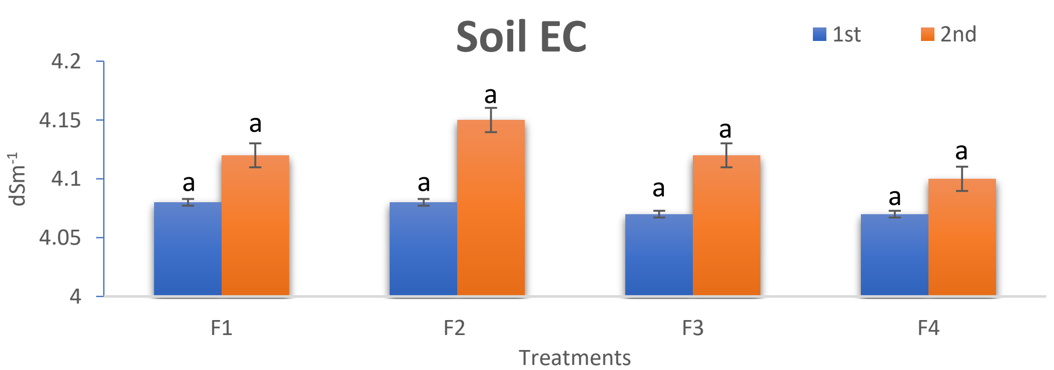

Fig 2. Effect of the cobalt, and molybdenum on soil EC value after harvesting soybean plants during seasons of 2022and 2023.

F_1: without application **(**control); **F_2:** Cobalt in the form of cobalt sulfate solution (36% Co); **F_3:** Molybdenum in the form of ammonium molybdate (48.9% Mo); **F_4:** combined application of Co + Mo.

4. Discussion

Growth criteria and leaf chemical constituents

Notably, adding compost resulted in the highest values for all studied growth parameters and leaf chemical constituents. This can be attributed to the rich organic content of compost, contributing essential nutrients, improving soil structure, and fostering a favorable environment for plant growth under saline conditions. The elevated levels of nitrogen (N), phosphorus (P), potassium (K), and chlorophyll observed with compost application indicate improved plant nutrition and physiological processes under the studied saline conditions. These results are in harmony with those of **Rady *et al.* (2016).**

The placement of gypsum as the second most effective treatment, following compost and preceding the control in the order of effectiveness, can be attributed to its specific benefits in addressing soil-related challenges, particularly in saline conditions. It may enhance the soil structure by promoting the aggregation of soil particles, leading to improved water infiltration and drainage. This restructuring mitigates the adverse effects of salinity by preventing waterlogging and facilitating the leaching of excess salts from the root zone **(Amer *et al.*, 2023).** Additionally, gypsum exhibits a unique ion exchange capacity, displacing sodium ions and promoting the retention of essential calcium ions in the soil. The calcium, in turn, helps ameliorate soil structure, reducing soil crusting and enhancing plant root development. **(Elsherpiny and Kany, 2023).**

On the other hand, the combined foliar application of cobalt and molybdenum exhibited maximum values for growth criteria and leaf chemical constituents. Cobalt and molybdenum are known micronutrients that are crucial in various metabolic processes, including chlorophyll synthesis and nitrogen metabolism. Their foliar application ensures direct and efficient uptake by the plant, leading to enhanced growth and improved nutritional status **(Akeel and Jahan 2020; Hu *et al.* 2021; Moussa *et al*. 2022).** Cobalt played a vital role in promoting soybean plant resilience and growth under salinity conditions by amino acid synthesis, enzyme activation, and supporting overall cellular functions. As salinity stress often disrupts normal plant physiological processes, including cobalt becomes crucial for maintaining a balanced and functional metabolism in the presence of elevated salt levels in the soil **(Baddour *et al.*, 2021).** Also, molybdenum plays a crucial role in nitrogen metabolism, amino acid synthesis, enzyme activation, phosphorus utilization, sulfur metabolism, and the mitigation of salinity stress in plants. Its involvement in these processes underscores its significance in maintaining plant health and productivity in saline environments **(Rana *et al.*, 2020).**

The consistent trend observed in both seasons, with the combined treatment of compost, cobalt (Co), and molybdenum (Mo) **(T_3 X F_4)** being the most effective, reinforces the notion that a synergistic approach involving soil amendment and foliar application can optimize soybean productivity. The combination likely addresses soil and plant-specific requirements, promoting overall plant health and performance under salt-affected soil.

Oxidative stress indicators

The observed trends in oxidative stress indicators in soybean leaves can be attributed to the influence of applied amendments and foliar treatments. Regarding antioxidant enzymes, the higher values of catalase (CAT) and peroxidase (POD) upon compost addition suggest that the organic matter content and nutrient availability from compost may enhance enzymatic activity. Agricultural gypsum, although trailing compost, still showed higher enzyme values than the control, indicating a positive impact on the antioxidant defense system. Conversely, the combined foliar application of cobalt and molybdenum resulted in elevated enzyme levels, suggesting a synergistic effect of these micronutrients on antioxidant enzyme activity. **(Akeel and Jahan 2020; Hu *et al.* 2021; Moussa *et al*. 2022).**

In contrast, proline and malondialdehyde (MDA) exhibited an inverse relationship, with higher levels observed in control treatments. The decline in proline and MDA levels with compost or gypsum addition implies potentially alleviating oxidative stress, possibly through improved plant water status and reduced lipid peroxidation. The foliar application of cobalt and molybdenum, either singly or in combination, also reduced proline and MDA levels, indicating a mitigating effect on oxidative stress. These results are in harmony with those of **Elsherpiny and Kany (2023).**

Yield and its components

The order of effectiveness for soil addition treatments was **T_3** (compost) > **T_2** (gypsum) > **T_1** (control), with compost exhibiting the highest increases in soybean quantitative and qualitative yield. This aligns with the earlier observations on growth criteria, reinforcing the pivotal role of compost in enhancing overall plant productivity under saline conditions.

The combined foliar application of cobalt and molybdenum (**F_4**) emerged as the superior treatment, emphasizing the synergistic effects of these micronutrients in promoting optimal yield and biochemical composition. Generally, the superiority of the **F_4** treatment lies in the synergistic and complementary actions of cobalt and molybdenum. These micronutrients work together to optimize nitrogen metabolism, amino acid synthesis, enzyme activation, and overall metabolic functions, providing a well-rounded solution to the challenges imposed by salinity stress on plant growth and productivity.

The continued effectiveness of the compost, cobalt, and molybdenum combination underscores its robust impact on soybean productivity. The interplay between soil amendment and foliar application appears to create a holistic approach to address soybeans' complex nutritional and growth requirements in a saline environment. These results are in harmony with those of **Rady *et al.* (2016), Rana *et al.* (2020)**, **Amer *et al.* (2023); and Elsherpiny and Kany (2023).**

Post-harvest soil analyses

The significant impact of both compost and gypsum on soil traits emphasizes their role in influencing the post-harvest soil environment. Compost, contributing to increased EC, may lead to enhanced organic matter content, hence nutrient availability such as N, P, K, and improved soil structure. This contrasts with gypsum, which decreased EC, highlighting its role in addressing sodicity issues by replacing sodium with calcium, thereby improving soil structure.

The non-significant effect of foliar treatments (Mo and Co) on post-harvest soil properties suggests that their impact is primarily directed toward plant physiology and yield rather than altering soil characteristics. The observed increase in available soil nitrogen under the control treatment could be attributed to the rhizobium inoculant, illustrating its effectiveness in influencing nitrogen levels in the soil. Similar results were observed by **Baddour *et al.* (2021) Elsherpiny and Kany (2023).**

5. Conclusion

In conclusion, this research underscores the significance of addressing saline soil challenges to enhance soybean productivity. Through a comprehensive evaluation of soil amendments and beneficial elements, it was determined that the combined treatment of compost **(T_3)** and the combined application of cobalt and molybdenum **(F_4)** emerged as the most effective approach for optimizing soybean growth and yield in saline conditions. Notably, compost addition demonstrated superiority in promoting growth parameters and nutrient availability, while gypsum contributed to a reduction in soil electrical conductivity. These findings emphasize the potential of strategic soil management practices to mitigate the impact of salinity on crop performance. Therefore, it is recommended that farmers and agricultural practitioners consider the integration of compost and the combined application of cobalt and molybdenum for sustainable soybean cultivation in saline soils, fostering increased agricultural resilience and productivity.

Conflicts of interest

The authors have declared that no competing interests exist.

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6. References

Ábrahám, E., Hourton-Cabassa, C., Erdei, L., & Szabados, L. (2010). Methods for determination of proline in plants. Plant stress tolerance: methods and protocols, 317-331.

Akeel, A., & Jahan, A. (2020). Role of cobalt in plants: its stress and alleviation. Contaminants in agriculture: sources, impacts and management, 339-357.

Alici, E. H., & Arabaci, G. (2016). Determination of SOD, POD, PPO and cat enzyme activities in Rumex obtusifolius L. Annual Research & Review in Biology, 1-7.

Amer, M. M., Aboelsoud, H. M., Sakher, E. M., & Hashem, A. A. (2023). Effect of gypsum, compost, and foliar application of some nanoparticles in improving some chemical and physical properties of soil and the yield and water productivity of faba beans in salt-affected soils. Agronomy, 13(4), 1052.

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

Babenko, O. N., Brychkova, G., Sagi, M., & Alikulov, Z. A. (2015). Molybdenum application enhances adaptation of crested wheatgrass to salinity stress. Acta physiologiae plantarum, 37, 1-13.

Baddour, A. G., El-Sherpiny, M. A., & Sakara, H. M. (2021). Effect of rhizobium inoculant, nitrogen starter and cobalt on stimulation of nodulation, n fixation and performance of faba bean (*Vicia faba* L.) grown under salinity stress. Journal of Soil Sciences and Agricultural Engineering, 12 (2), 61-69.

Duncan, D. B. (1955). Multiple range and multiple F tests. Biometrics, 11(1), 1-42.

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.

Elsherpiny, M. A. (2023). Effect of organic amendments and synthetic substances on copper availability, absorption, and wheat productivity. Egyptian Journal of Soil Science, 63(3), 429-442.

Elsherpiny, M. A., & Kany, M.A. (2023). Maximizing faba bean tolerance to soil salinity stress using gypsum, compost and selenium. Egyptian Journal of Soil Science, 63(2), 243-253.

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.

Gee, G.W. and J.W. Bauder. (1986). Particle-size Analysis. p 383-411 In A. Klute (ed.) Methods of Soil Analysis Part 1. Soil Science Society of America Book Series 5, Madison, Wisconsin, USA.

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

Hu, X., Wei, X., Ling, J., & Chen, J. (2021). Cobalt: an essential micronutrient for plant growth?. Frontiers in plant science, 12, 768523.

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.

Mendes, R., Cardoso, C., & Pestana, C. (2009). Measurement of malondialdehyde in fish: A comparison study between HPLC methods and the traditional spectrophotometric test. Food Chemistry, 1 12 (4), 1038-1045.

Morsy, S., Elbasyoni, I. S., Baenziger, S., & Abdallah, A. M. (2022). Gypsum amendment influences performance and mineral absorption in wheat cultivars grown in normal and saline-sodic soils. Journal of Agronomy and Crop Science, 208(5), 675-692.

Moussa, M. G., Sun, X., Ismael, M. A., Elyamine, A. M., Rana, M. S., Syaifudin, M., & Hu, C. (2022). Molybdenum-induced effects on grain yield, macro–micro-nutrient uptake, and allocation in Mo-inefficient winter wheat. Journal of Plant Growth Regulation, 41(4), 1516-1531.

Rady, M. M., Semida, W. M., Hemida, K. A., & Abdelhamid, M. T. (2016). The effect of compost on growth and yield of *Phaseolus vulgaris* plants grown under saline soil. International Journal of Recycling of Organic Waste in Agriculture, 5, 311-321.

Rana, M., Bhantana, P., Sun, X. C., Imran, M., Shaaban, M., Moussa, M., ... & Hu, C. X. (2020). Molybdenum as an essential element for crops: an overview. Int. J. Sci. Res. Growth, 24(18535).

Shaygan, M., & Baumgartl, T. (2022). Reclamation of salt-affected land: A review. Soil Systems, 6(3), 61.

Tandon, H. L. S. (2005). Methods of analysis of soils, plants, waters, fertilisers & organic manures. Fertiliser Development and Consultation Organisation.

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

Yan, Y. F., Lee, K. J., & Lee, B. W. (2007). Using chlorophyll (SPAD) meter reading and shoot fresh weight for recommending nitrogen topdressing rate at panicle initiation stage of rice. *Journal of* Crop Science and Biotechnology, 10(1), 33-38.