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Evaluation of Cobalt Application Combined with Gypsum and Compost as a Regulator of Cabbage Plant Tolerance to Soil Salinity

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Abstract

In response to the global food crisis and the imperative to address soil degradation, the international agricultural policy is actively working to alleviate the adverse impacts of soil salinity. As part of this initiative, a field trial spanning two consecutive seasons (2019/20-2020/21) was conducted under saline conditions. The primary objective was to evaluate the influence of various compost sources, including vermicompost at a rate of 0.5 ton·fed^{-1} and plant residues compost at a rate of 5.0 ton·fed^{-1}, as main plots. Subplots were established by applying agricultural gypsum, both in the presence and absence of gypsum requirements. Additionally, sub-subplots were created by externally applying cobalt at a rate of 10.0 mg·L^{-1}, with one sub-subplot receiving foliar cobalt application and the other not. The trial sought to assess the growth performance, chemical composition, enzymatic antioxidants, yield, and quality of cabbage plants (*Brassica oleracea* var. capitata L.) cultivated in saline soil. According to the findings, cabbage plants exhibited the most favorable response in terms of plant height, chlorophyll content, carotene levels, leaf area, nitrogen (N), phosphorus (P), potassium (K), head yield, vitamin C, and total dissolved solids (TDS) when treated with vermicompost, followed by plant compost. Conversely, plants grown without compost exhibited the least improvement in performance. Cabbage treated with agricultural gypsum requirements showed better performance than those without gypsum amendment. Moreover, plants subjected to cobalt spray demonstrated the highest growth, yield, and quality parameters compared to those without cobalt foliar application. In contrast, the control group (plants without the studied treatments) displayed the highest levels of enzymatic antioxidants, specifically catalase and peroxidase. This indicates that soil salinity stress led to an increase in catalase and peroxidase production in cabbage plants as a defense against the harmful impact of reactive oxygen species (ROS) resulting from soil salinity stress. The applied treatments (compost, gypsum, and cobalt) led to a reduction in the cabbage plant's inherent production of catalase and peroxidase. Generally, the combined treatment of vermicompost × gypsum requirements × cobalt proved effective in mitigating the detrimental effects of soil salinity on cabbage plants. These findings hold significance for farmers and policymakers aiming to enhance agricultural productivity in regions affected by soil salinity. Additionally, further research can explore the long-term effects of these treatments on soil health and crop sustainability.

Keywords

Vermicompost, Plant Compost, Gypsum Requirements, Cobalt, Soil Health and Crop Sustainability

1. Introduction

While humanity lacks control over environmental stressors, individuals must comprehend how stressors impact plants and other organisms. This understanding enables the implementation of preventive measures [1]. Salinity stress stands out as a highly damaging abiotic stress factor that negatively influences the growth, productivity, and physiology of plants [2]. Saline soil, characterized by the accumulation of excessive salts, typically manifests visibly on the soil surface [3]. Natural capillary action transports salt to the soil surface, loading it from saline groundwater, and subsequent accumulation occurs through evaporation. Human activities can further contribute to the density of salinity in the soil [4]. As soil salinity intensifies, the detrimental effects of salt increase, potentially leading to the degradation of both soil and plants [5]. The elevated salinity hinders the plant's absorption of certain elements, and an increased intake of salts can result in ionic poisoning of the cell. Additionally, the rise in salt levels leads to a reduction in water absorption by the plant due to the high osmosis of soil water [6]. Soil salinity exerts a harmful impact, resulting in a reduction in the yield of all crops [7]. This influence adversely affects plant growth by diminishing leaf water potential, triggering morphological and physiological changes, disrupting biochemical processes, generating reactive oxygen species (ROS), and escalating ion toxicity and osmotic stress [8] [9].

To safeguard higher plants from the detrimental impact of saline soil, an effective approach involves the use of soil organic fertilizers. These fertilizers have the potential to supply essential nutrients to plants thriving in salt-affected soil [10]. Additionally, they play a role in enhancing and improving soil properties, which in turn positively influence the nutritional components of vegetable crops [11]. Vermicompost, a nourishing organic fertilizer, contains beneficial soil microbes such as "nitrogen-fixing bacteria" and mycorrhizal fungi, along with substantial levels of nitrogen (2% - 3%), phosphorus (1.55% - 2.25%), potassium (1.85% - 2.25%), humus, and micronutrients [12]. The production of vermicompost involves the biodegradation of organic substances through interactions between earthworms and microorganisms [13]. It has been known that sodium and magnesium possess a negative impact on soil's attributes when their levels are relatively high compared with calcium [14]. Agricultural gypsum has become an efficient soil amendment for reclaiming salt-affected soil of poor aggregation or soil structure [10]. Its application increases soluble Ca^{2+} in the soil solution to substitute the adsorbed Na^{+}, thus overcoming the dispersion impacts of Na^{+} and improving the soil structure in the dispersed saline soils [7]. Another protective method against soil salinity stress involves the exogenous application of cobalt [15]. This application has the potential to enhance various plant tolerances to salinity conditions [16], thereby positively impacting the growth performance of higher plants and mitigating the adverse effects of salinity stress [17]. While cobalt was previously considered solely beneficial for higher plants, it is now officially classified as an essential element for higher plants, as indicated in REGULATION (EU) 2019/1009 by the Official Journal of the European Union [18]. Cabbage (*Brassica oleracea var. capitata* L.) holds significance as a crucial leafy vegetable cultivated globally and belongs to the Brassicaceae family [19]. It is known for its rich nutritional profile, containing vitamins A, B1, B2, and C, along with antioxidants, riboflavin, carotenoids, thiamine, minerals, and polyphenols [20].

So, the specific objectives of the current study were to evaluate the cobalt application combined with gypsum and compost as a regulator of cabbage plant tolerance to soil salinity.

2. Materials and Methods

2.1. Experimental Location

The current research work was executed during two successive seasons (2019/20-2020/21) in the Experimental Farm of the Faculty of Agriculture, Mansoura Univ., El-Dakahlia Governorate, Egypt (31˚03'00"N 31˚22'59"E).

2.2. Initial Soil Analysis

Before transplanting the seedlings, a composite initial soil sample was taken for analysis depending on Dane and Topp [21] and Sparks *et al.*, [22]. **Table 1** indicates its characteristics.

2.3. Preparation of the Substances Studied

Compost: Plant residues *i.e.*, maize stock, soybean, wheat, and chickpea residues) was obtained and then composted at the site of the experiment depending on El-Hammady *et al.*, [23].

Vermicompost: It was prepared using Earthworm (*Eisenia fetida*) depending on Wako, [24] using the same previous plant residues. The collected substrates were chopped and added to the worm bin.

Agricultural gypsum ($CaSO_4$. $2H_2O$): It was obtained from El Shafeey company, Giza, Egypt, and has a calcium content of 22.9 g/100g^{-1}, sulfur content of 17.9 g/100g^{-1}, pH value of 7.8 and EC value of 2.5 dSm^{-1} (1:5 agricultural gypsum amendment: water). Gypsum requirements (GR equivalent 2.80 ton·fed^{-1}) were measured according to FAO and IIASA [25] as follows:

$$\text{GR} = \frac{\text{Initial soil ESP}(13.9\%) - \text{Required soil ESP}(10\%)}{100} \times \text{CEC}\left(42.0\ \text{cmol}\cdot\text{kg}^{-1}\right) \times 1.72 \times \text{CEC}\left(42.0\ \text{cmol}\cdot\text{kg}^{-1}\right) \times 1.72$$

Cobalt: Cobalt sulfate ($CoSO_4$, 38.022% Co) was obtained from El-Gamhoria Company, Egypt, and then its solution was prepared by dissolving a known mass of the compound in the solvent, and then prepared the studied rate (10.0 mg·L^{-1}).

Table 2 shows the properties of both studied compost sources.

2.4. Application time of the Substances studied

Compost and vermicompost: They were thoroughly mixed with the surface

Table 1. Characteristics of the initial soil taken at a depth of 0.0 - 30 cm before transplanting.

Soil characteristics		Values
Organic matter,%		1.45
pH (1:2.5 soil suspension)		8.20
EC dSm^{-1}		6.85
Available nitrogen		58.5
Available phosphorus	**(mg·kg^{-1})**	8.20
Available potassium		275
Texture class is clayey		
Sand		14.00
Silt	**(%)**	35.20
Clay		50.80

Table 2. Properties of both studied compost sources.

Parameters	Vermicompost	Plant residues compost
EC dSm^{-1}	2.61	3.35
pH	7.0	6.35
P $mg \cdot kg^{-1}$	2.29	0.72
K $mg \cdot kg^{-1}$	1.31	0.89
Mn $mg \cdot kg^{-1}$	37.0	27.0
Zn $mg \cdot kg^{-1}$	38.0	22.0
C:N ratio	11.76	12.4
Total C %	20.00	19.41
Total N %	1.70	1.56

of the studied saline soil layer (0 - 30 cm) in a single application one month before transplanting.

Agricultural gypsum ($CaSO_4$. $2H_2O$): It was thoroughly mixed with the surface of the studied saline soil layer (0 - 30 cm) in a single application four before transplanting. During the four months before transplanting, the studied saline soil was irrigated after gypsum soil addition up to the saturation limit every 20 days to get rid of Na^+. The height of added irrigation water above the studied saline soil surface was about 10 cm.

Cobalt: Foliar application of cobalt solution was sprayed at three stages (20, 40 and 60 days after transplanting) by hand sprayer until saturation point with the volume of 450 $L \cdot fed^{-1}$.

2.5. Experimental Setup

A field trial was conducted under a split-plot design with three replicates aiming to evaluate the impact of different compost sources *i.e.*, vermicompost at rate of 0.5 $ton \cdot fed^{-1}$ and plant residues compost at rate of 5.0 $ton \cdot fed^{-1}$ as main plots as well as agricultural gypsum [once in the presence of gypsum requirements (2.80 $ton \cdot fed^{-1}$) and other in the absence of gypsum requirements] as subplots and exogenous application of cobalt as sub-subplots at rate of 10.0 $mg \cdot L^{-1}$ [once with foliar application of cobalt and other in the absence of cobalt] on the growth performance, chemical constituents, enzymatic antioxidants, yield and quality of cabbage plant grown on saline soil.

Cabbage seedlings **(cv. Brunswick, 45 days old)** took place at the field on 25th of December during both growing seasons with a planting distance of 0.85 m apart within rows and 75 cm. between rows, where the sub subplot area was 20.0 m^2.

Irrigation process, mineral fertilization (N, P and K) and the other common agricultural practices for cabbage production were carried out as recommended by The Ministry of Agriculture.

2.6. Harvest

The Harvest process was done after 75 days after transplanting.

2.7. Measurements

At harvesting time, cabbage plant samples were taken randomly from each experimental sub sub-plot to record the following criteria:

1) Growth parameters: Plant height (cm) and leaf area (cm^2).

2) Photosynthetic pigments: Chlorophyll (SPAD) and carotene content ($mg \cdot g^{-1}$) were determined spectrophotometrically by the procedure postulated by Ranganna [26].

3) Chemical constituents: N (Kjeldahl method), P (spectrophotometer method), K (flam photometer method) were estimated in cabbage leaves according to Walinga *et al.*, [27]. The oven-dried samples were wet digested by a mixture of perchloric and sulfuric acids (1:1) according to the method of Peterburgski, [28].

4) Enzymatic antioxidants: catalyze and peroxidases ($\Delta A \cdot min^{-1} \cdot 0g^{-1}$, FW) were determined as described by Alici and Arabaci, [29].

5) Head quality attributes: Head length and diameter (cm), No of wrapper leaves, average head weight (kg) and head yield ($ton \cdot ha^{-1}$).

6) Quality traits: Using a hand Refractometer, TDS (total dissolved solids, %) was determined according to AOAC, [30]. Vitamin C (VC, $mg/100g^{-1}$) was estimated via titration with 2.6 diclorophenol indophenol blue dye according to AOAC, [30]. Samples were oven-dried at 60˚C until constant weight, and then dry matter percent was calculated.

2.8. Statistical Analysis

Statistical analysis of the obtained data was done according to Gomez and Gomez [31].

3. Results

Data tabled show the individual effect impact of two types of compost sources *i.e.*, vermicompost and plant residues compost as well as gypsum and cobalt and their interactions on the performance of cabbage plants grown on salt-affected soil during seasons of 2019/2020 and 2020/2021. Growth performance *i.e.*, plant height (cm) and leaf area (cm^2) and photosynthetic pigments *i.e.*, chlorophyll (SPAD) and carotene content ($mg \cdot g^{-1}$) were shown in **Table 3**, while leaves chemical constituents *i.e.*, N, P and K were illustrated **Table 4**. **Table 5** indicates head quality attributes *i.e.*, head length and diameter (cm), No of wrapper leaves, average head weight (kg) and head yield ($ton \cdot h^{-1}$), while **Table 6** indicates quality traits *i.e.*, vitamin C ($mg/100g^{-1}$), total dissolved solids (TDS, %) and dry matter (DM, %). Finally, **Table 7** indicates enzymatic antioxidants *i.e.*, catalyze and peroxidase ($\Delta A \cdot min^{-1} \cdot g^{-1}$, FW).

3.1. Growth Performance, Quality, Yield, and Its Components

Individual effect of different compost sources: The results indicated that the cabbage plant responded best to vermicompost compared to plant compost, while the control treatment (plants grown without compost) had the least response

Table 3. The Effect of cobalt application combined with gypsum and compost on the performance of cabbage plants expressed in plant height, chlorophyll and carotene contents and leaf area during seasons of 2019/2020 and 2020/2021.

Treatments			Plant height, (cm)		Chlorophyll, SPAD		Carotene, $mg \cdot g^{-1}$		Leaf area, cm^2	
			1st	2nd	1st	2nd	1st	2nd	1st	2nd
Compost soil addition										
Vermicompost (0.5 $ton \cdot fed^{-1}$)			35.76a	36.86a	44.50a	44.98a	0.585a	0.596a	650.83a	659.33a
Plant compost (5.0 $ton \cdot fed^{-1}$)			33.89b	34.99b	43.86b	44.43b	0.563b	0.572b	637.92b	646.17b
Control (without addition)			29.18c	30.10c	42.21c	42.73c	0.512c	0.521c	605.92c	614.25c
LSD at 5%			**0.36**	**0.53**	**0.03**	**0.10**	**0.001**	**0.001**	**1.49**	**1.36**
Gypsium soil addition										
Check treatment			31.37b	32.34b	43.02b	43.54b	0.537b	0.546b	620.89b	628.78b
Gypsium (GR)			34.52a	35.63a	44.03a	44.55a	0.570a	0.580a	642.22a	651.06a
LSD at 5%			**0.24**	**0.32**	**0.16**	**0.12**	**0.002**	**0.002**	**0.51**	**0.49**
Cobalt foliar application										
Check treatment			32.48b	33.48b	43.36b	43.87b	0.548b	0.558b	627.67b	635.83b
Cobalt (10.0 mg Co L^{-1})			33.41a	34.49a	43.68a	44.23a	0.558a	0.568a	635.44a	644.00a
LSD at 5%			**0.35**	**0.26**	**0.14**	**0.13**	**0.001**	**0.001**	**0.44**	**0.45**
Interaction										
Vermicompost	Check treatment	Check treatment	33.44e	34.51f	43.80cd	44.28cd	0.559f	0.571f	634.00f	644.00f
		Cobalt	34.31d	35.37e	43.94c	44.35cd	0.570e	0.580e	641.33e	649.33e
	Gypsium	Check treatment	37.18b	38.30b	45.06ab	45.59ab	0.600b	0.612b	659.00b	668.00b
		Cobalt	38.10a	39.27a	45.19a	45.71a	0.611a	0.623a	669.00a	676.00a
Plant compost	Check treatment	Check treatment	31.60g	32.44h	43.22e	43.77e	0.538h	0.547h	622.00h	628.00h
		Cobalt	32.53f	33.76g	43.47de	44.13d	0.546g	0.557g	629.33g	636.33g
	Gypsium	Check treatment	35.30c	36.51d	43.94c	44.47c	0.580d	0.591d	646.33d	655.33d
		Cobalt	36.14c	37.23c	44.81b	45.36b	0.587c	0.594c	654.00c	665.00c
Control (without addition)	Check treatment	Check treatment	27.61k	28.36l	41.66h	42.17i	0.498l	0.503l	596.33l	603.33l
		Cobalt	28.73j	29.57k	42.02g	42.55h	0.509k	0.520k	602.33k	611.67k
	Gypsium	Check treatment	29.72i	30.77j	42.50f	42.92g	0.516j	0.526j	608.33j	616.33j
		Cobalt	30.65h	31.72i	42.66f	43.28f	0.526i	0.536i	616.67i	625.67i
LSD at 5%			**0.86**	**0.63**	**0.35**	**0.32**	**0.002**	**0.002**	**1.07**	**1.11**

Table 4. The Effect of cobalt application combined with gypsum and compost on leaves chemical constituents of cabbage during seasons of 2019/2020 and 2020/2021.

Treatments	N, %		P, %		K, %	
	1st	2nd	1st	2nd	1st	2nd
Compost soil addition						
Vermicompost (0.5 $ton \cdot fed^{-1}$)	3.64a	3.69a	0.499a	0.509a	2.97a	3.00a
Plant compost (5.0 $ton \cdot fed^{-1}$)	3.48b	3.52b	0.474b	0.481b	2.87b	2.90b

Continued

Control (without addition)			3.02c	3.07c	0.406c	0.414c	2.54c	2.58c
LSD at 5%			**0.01**	**0.01**	**0.002**	**0.002**	**0.06**	**0.05**
Gypsium soil addition								
Check treatment			3.22b	3.27b	0.439b	0.447b	2.70b	2.74b
Gypsium (GR)			3.54a	3.58a	0.480a	0.488a	2.89a	2.92a
LSD at 5%			**0.07**	**0.07**	**0.001**	**0.001**	**0.01**	**0.04**
Cobalt foliar application								
Check treatment			3.34b	3.39b	0.453b	0.461b	2.76b	2.79b
Cobalt (10.0 mg Co L^{-1})			3.42a	3.46a	0.466a	0.475a	2.83a	2.86a
LSD at 5%			**0.06**	**0.06**	**0.001**	**0.001**	**0.03**	**0.07**
Interaction								
Vermicompost	Check treatment	Check treatment	3.39ef	3.43ef	0.468f	0.477f	2.82ef	2.86cd
		Cobalt	3.50de	3.55de	0.481e	0.491e	2.89de	2.92bcd
	Gypsium	Check treatment	3.81ab	3.85ab	0.517b	0.526b	3.05ab	3.09a
		Cobalt	3.87a	3.91a	0.530a	0.541a	3.10a	3.14a
Plant compost	Check treatment	Check treatment	3.28fg	3.33fg	0.442h	0.450h	2.74g	2.77de
		Cobalt	3.31f	3.34fg	0.456g	0.461g	2.78fg	2.82cde
	Gypsium	Check treatment	3.63cd	3.67cd	0.492d	0.497d	2.94cd	2.98abc
		Cobalt	3.70bc	3.75bc	0.505c	0.516c	3.01bc	3.05ab
Control (without addition)	Check treatment	Check treatment	2.89j	2.92j	0.387l	0.395l	2.42j	2.47g
		Cobalt	2.98ij	3.03ij	0.401k	0.409k	2.53i	2.58fg
	Gypsium	Check treatment	3.05hi	3.11hi	0.411j	0.419j	2.58hi	2.61fg
		Cobalt	3.15gh	3.21gh	0.424i	0.433i	2.65h	2.68ef
LSD at 5%			**0.15**	**0.15**	**0.002**	**0.002**	**0.08**	**0.16**

Table 5. The Effect of cobalt application combined with gypsum and compost on head physical qualities of cabbage and yield during seasons of 2019/2020 and 2020/2021.

Treatments	Head length, cm		Head diameter, cm		No of wrapper leaves		Average head weight, kg		Head yield, ton·h^{-1}	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Compost soil addition										
Vermicompost (0.5 ton·fed^{-1})	21.48a	21.69a	26.54a	26.82a	62.25a	62.00a	2.38a	2.41a	87.46a	88.75a
Plant compost (5.0 ton·fed^{-1})	20.69b	20.97b	25.03b	25.37b	57.67b	54.75b	2.27b	2.30b	83.44b	84.64b
Control (without addition)	18.69c	18.94c	21.26c	21.59c	44.17c	45.33c	1.89c	1.92c	69.52c	70.75c
LSD at 5%	**0.16**	**0.31**	**0.04**	**0.04**	**3.61**	**10.24**	**0.02**	**0.04**	**0.89**	**1.56**
Gypsium soil addition										
Check treatment	19.62b	19.87b	23.04b	23.35b	50.83b	48.28b	2.10b	2.13b	77.14b	78.26b

Continued

Gypsium (GR)			20.95a	21.20a	25.52a	25.84a	58.56a	59.78a	2.26a	2.30a	83.15a	84.50a
LSD at 5%			**0.13**	**0.12**	**0.34**	**0.34**	**0.45**	**6.77**	**0.02**	**0.03**	**0.59**	**1.08**
Cobalt foliar application												
Check treatment			20.07b	20.32b	23.90b	24.21b	53.33b	51.28a	2.15b	2.19b	79.14b	80.41b
Cobalt (10.0 mg Co L^{-1})			20.50a	20.75a	24.65a	24.98a	56.06a	56.78a	2.21a	2.24a	81.14a	82.35a
LSD at 5%			**0.26**	**0.22**	**0.26**	**0.26**	**1.70**	**n.s**	**0.02**	**0.05**	**0.82**	**1.78**
Interaction												
Vermicompost	Check treatment	Check treatment	20.50ef	20.69ef	24.68f	24.93e	57.33cd	54.33a-d	2.27d	2.30de	83.54d	84.52de
		Cobalt	20.89de	21.09de	25.43e	25.68d	59.33c	5abc9.67	2.31cd	2.35cde	85.01cd	86.48cde
	Gypsium	Check treatment	22.05ab	22.28ab	27.64b	28.00b	64.67ab	65.3ab3	2.44a	2.48ab	89.79a	91.26ab
		Cobalt	22.49a	22.70a	28.40a	28.69a	67.67a	68.67a	2.49a	2.52a	91.51a	92.74a
Plant compost	Check treatment	Check treatment	19.70gh	19.96gh	23.15h	23.43g	52.67e	37.67e	2.14f	2.17f	78.75f	79.86f
		Cobalt	20.10fg	20.41fg	23.88g	24.19f	53.67de	54.33a-d	2.21e	2.24ef	81.33e	82.31ef
	Gypsium	Check treatment	21.28cd	21.59cd	26.17d	26.48c	60.67bc	62.33abc	2.34bc	2.38bcd	86.11bc	87.46bcd
		Cobalt	21.68bc	21.94bc	26.93c	27.36b	63.67ab	64.67ab	2.38b	2.42abc	87.58b	88.93abc
Control (without addition)	Check treatment	Check treatment	18.05k	18.31k	20.17l	20.57j	39.67g	41.00de	1.79j	1.82i	65.75j	66.98i
		Cobalt	18.51jk	18.76jk	20.90k	21.28i	42.33fg	42.67de	1.86i	1.89hi	68.45i	69.43hi
	Gypsium	Check treatment	18.87ij	19.09ij	21.60j	21.84i	45.00f	47.00cde	1.93h	1.97gh	70.90h	72.38gh
		Cobalt	19.33gh	19.62hi	22.36i	22.67h	49.67e	50.67b-e	1.98g	2.02g	72.99g	74.22g
LSD at 5%			**0.65**	**0.54**	**0.64**	**0.64**	**4.16**	**15.36**	**0.06**	**0.12**	**2.02**	**4.37**

Table 6. The Effect of cobalt application combined with gypsum and compost on the quality of cabbage during the seasons of 2019/2020 and 2020/2021.

Treatments	TDS, %		Vitamin C, mg/$100g^{-1}$		Dry matter, %	
	1st	2nd	1st	2nd	1st	2nd
Compost soil addition						
Vermicompost (0.5 ton·fed^{-1})	7.71a	7.83a	34.79a	34.99a	9.55a	9.74a
Plant compost (5.0 ton·fed^{-1})	7.46b	7.59b	34.06b	34.21b	9.34b	9.50b
Control (without addition)	7.01c	7.10c	32.16c	32.31c	8.81c	8.95c
LSD at 5%	**0.05**	**0.12**	**0.18**	**0.03**	**0.14**	**0.02**
Gypsium soil addition						
Check treatment	7.22b	7.33b	33.05b	33.17b	9.03b	9.19b
Gypsium (GR)	7.56a	7.68a	34.29a	34.50a	9.43a	9.60a
LSD at 5%	**0.10**	**0.09**	**0.18**	**0.18**	**0.09**	**0.01**
Cobalt foliar application						
Check treatment	7.35b	7.46a	33.45b	33.63b	9.17b	9.33b
Cobalt (10.0 mg Co L^{-1})	7.44a	7.55a	33.89a	34.04a	9.30a	9.46a
LSD at 5%	**0.05**	**n.s**	**0.17**	**0.07**	**0.07**	**0.01**

Continued

Interaction								
Vermicompost	Check treatment	Check treatment	7.42ef	7.53c-f	33.86d	33.94f	9.27ef	9.47f
		Cobalt	7.53de	7.64b-e	34.27c	34.38e	9.37de	9.56e
	Gypsium	Check treatment	7.87b	8.00ab	35.14b	35.60b	9.71ab	9.90b
		Cobalt	8.02a	8.14a	35.87a	36.04a	9.83a	10.02a
Plant compost	Check treatment	Check treatment	7.19gh	7.31efg	33.12ef	33.31h	9.06gh	9.20h
		Cobalt	7.30fg	7.41d-g	33.46de	33.58g	9.17fg	9.33g
	Gypsium	Check treatment	7.63cd	7.76a-d	34.59c	34.70d	9.51cd	9.70d
		Cobalt	7.71c	7.87abc	35.07b	35.22c	9.63bc	9.77c
Control (without addition)	Check treatment	Check treatment	6.94j	7.03g	31.63h	31.71l	8.55k	8.67l
		Cobalt	6.97j	7.06g	31.94h	32.12k	8.79j	8.92k
	Gypsium	Check treatment	7.02ij	7.12fg	32.35g	32.50j	8.89ij	9.03j
		Cobalt	7.11hi	7.20fg	32.73fg	32.90i	8.99hi	9.16i
LSD at 5%			**0.12**	**0.42**	**0.41**	**0.17**	**0.16**	**0.02**

Table 7. The Effect of cobalt application combined with gypsum and compost on the cabbage plant's self-production from enzymatic antioxidants during the seasons of 2019/2020 and 2020/2021.

Treatments			Catalyze, mM H_2O_2 $min^{-1}\cdot g^{-1}$ (FW)		Peroxidase, $\Delta A\cdot min^{-1}\cdot g^{-1}$ (FW)	
			1st	2nd	1st	2nd
Compost soil addition						
Vermicompost (0.5 ton·fed^{-1})			23.08c	23.55c	171.09c	174.55c
Plant compost (5.0 ton·fed^{-1})			23.73b	24.19b	172.37b	175.28b
Control (without addition)			25.57a	26.10a	175.70a	178.57a
LSD at 5%			**0.02**	**0.01**	**0.48**	**0.11**
Gypsium soil addition						
Check treatment			24.72a	25.22a	174.13a	177.11a
Gypsium (GR)			23.54b	24.00b	171.98b	175.17b
LSD at 5%			**0.04**	**0.13**	**0.27**	**0.21**
Cobalt foliar application						
Check treatment			24.32a	24.81a	173.34a	176.46a
Cobalt (10.0 mg Co L^{-1})			23.93b	24.42b	172.77a	175.82b
LSD at 5%			**0.02**	**0.06**	**n.s**	**0.12**
Interaction						
Vermicompost	Check treatment	Check treatment	23.89g	24.37g	172.68def	176.42cd
		Cobalt	23.56h	24.02h	171.98efg	175.31e
	Gypsium	Check treatment	22.62k	23.07k	170.10hi	173.63g
		Cobalt	22.27l	22.72l	169.61i	172.85h

Continued

Plant compost	Check treatment	Check treatment	24.58e	25.11e	173.82bcd	176.63c
		Cobalt	24.27f	24.78f	173.37cde	176.26d
	Gypsium	Check treatment	23.18i	23.61i	171.52fgh	174.75f
		Cobalt	22.90j	23.26j	170.77ghi	173.50g
Control (without addition)	Check treatment	Check treatment	26.36a	26.78a	176.63a	179.07a
		Cobalt	25.64b	26.28b	176.27a	178.94a
	Gypsium	Check treatment	25.31c	25.92c	175.30ab	178.24b
		Cobalt	24.96d	25.43d	174.61bc	178.03b
LSD at 5%			**0.04**	**0.15**	**1.63**	**0.28**

and performance enhancement. Specifically, the plants treated with vermicompost had the highest values of plant height (cm), leaf area (cm^2), chlorophyll (SPAD), carotene content ($mg \cdot g^{-1}$), N, P and K, head length and diameter (cm), No of wrapper leaves, average head weight (kg) and head yield ($ton \cdot h^{-1}$),vitamin C ($mg/100g^{-1}$), total dissolved solids (TDS, %) and dry matter (DM, %). The plants treated with plant residues compost had slightly lower values than those treated with vermicompost, but still showed better performance compared to the control treatment.

Individual effect of agricultural gypsum: The findings presented in Tables 3-6 demonstrate that cabbage plants treated with agricultural gypsum had the highest values of plant height (cm), leaf area (cm^2), chlorophyll (SPAD), carotene content ($mg \cdot g^{-1}$), N, P and K, head length and diameter (cm), No of wrapper leaves, average head weight (kg) and head yield ($ton \cdot h^{-1}$), vitamin C ($mg/100g^{-1}$), total dissolved solids (TDS, %) and dry matter (DM, %). On the other hand, the lowest values were recorded for plants grown without gypsum amendment.

Individual effect of cobalt: Tables 3-6 demonstrate that the cabbage plants treated with foliar spray of cobalt exhibited higher values for growth, yield, and quality parameters than the plants grown without cobalt application.

Interaction effect: Also, as shown in Tables 3-6, the plants treated with the combined treatment of vermicompost × gypsum requirements × cobalt was useful in reducing harmful effect of soil salinity on cabbage plant and recorded the highest values of plant height (cm), leaf area (cm^2), chlorophyll (SPAD), carotene content ($mg \cdot g^{-1}$), N, P and K, head length and diameter (cm), No of wrapper leaves, average head weight (kg) and head yield ($ton \cdot h^{-1}$), vitamin C ($mg/100g^{-1}$), total dissolved solids (TDS, %) and dry matter (DM, %).

3.2. Enzymatic Antioxidants

Table 7 displays that the control cabbage plants (grown without any treatments) exhibited the highest levels of enzymatic antioxidants, specifically catalase and peroxidase. This suggests that soil salinity stress triggered an increase in the production of catalase and peroxidase in cabbage plants, as a defense mechanism against the harmful effects of ROS resulting from salinity stress. On the other hand, the application of the studied treatments (compost, gypsum, and cobalt) led to a decrease in the plant's self-production of catalase and peroxidase.

Individual effect of different compost sources: Contrary to the previous results, the highest values of catalyze and peroxidase ($\Delta A \cdot min^{-1} \cdot g^{-1}$, FW) were recorded with control treatment (without organic soil addition) followed by soil addition of plant residues compost then the vermicompost treatment.

Individual effect of agricultural gypsum: Table 7 shows that the highest values of aforementioned enzymatic antioxidants were recorded with control treatment (without gypsum soil addition) followed by gypsum treatment

Individual effect of cobalt: The same Table also, illustrates that the highest values of catalyze and peroxidase ($\Delta A \cdot min^{-1} \cdot g^{-1}$, FW) were achieved with control treatment (without foliar application of cobalt) followed by cobalt treatment.

Interaction effect: Also, as shown in Table 7, the cabbage plants treated with the combined treatment of vermicompost × gypsum requirements × cobalt recorded the lowest values of catalyze and peroxidase ($\Delta A \cdot min^{-1} \cdot g^{-1}$, FW).

4. Discussion

Generally, it can be said that both organic sources had a positive impact on improving the growth, quality, and yield of cabbage plants grown in saline soil, due to their ability to supply essential macro and micronutrients. Moreover, both sources may aid in increasing soil aggregates, facilitating leaching of salts away from the root zone. The superiority of vermicompost over plant residue compost may be attributed to its lower C/N ratio and higher nutrient content. Additionally, vermicompost may have a faster and more immediate effect compared to plant residue compost. Furthermore, the nutrients in vermicompost may dissolve easily in irrigation water, whereas those in plant residues compost may not be as readily available for the cabbage plant to utilize.

The superior performance of vermicompost may be attributed to its ability to facilitate and chelate solid elements in the soil, making it easier for the plant to absorb and benefit from them. Vermicompost not only supplies the plant with necessary major and minor elements but also provides a diverse range of bacteria that have multiple important functions for the plant. This means that it provides the soil with the ability to manufacture and create nutrients, growth regulators, and materials to resist soil pests, which helps to restore the soil's vitality. Vermicompost also contains antibiotics and fungi such as Actinomyces, which can raise the plant's biological resistance against insects and diseases, reducing the need for pesticide spraying. These findings are consistent with those of Rekha *et al.*, [12]; Ceritoğlu *et al.*, [13]; Abo El-Ezz *et al.*, [10] and Ghazi *et al.*, [11].

Agricultural gypsum may have been superior due to its ability to increase soil aggregates by providing Ca^{2+} ions that facilitate the formation of stable soil aggregates. This, in turn, leads to the leaching of salts with continuous soil irrigation before planting, as a result of the soil addition of gypsum. Moreover, the addition of agricultural gypsum might improve the properties of saline soil, leading to an increase in cabbage tolerance against salinity conditions. Agricultural gypsum has a Ca^{2+} content of 23%, which enables the displacement of Na^{+} ions on the cation exchange sites of the saline soil colloids. Therefore, the application of agricultural gypsum to saline soil could accelerate Na^{+} leaching, subsequently increasing the percentage of exchangeable calcium and decreasing the percentage of exchangeable sodium. The obtained results are in accordance with those of Ghazi *et al.*, [9]. The foliar application of cobalt resulted in more robust plant growth and superior performance, quality, and yield, owing to its ability to stimulate growth during various physiological stages. These findings are consistent with those of Baddour *et al.* [15], who reported that cobalt can mitigate the adverse effects of salinity and enhance the plant's ability to withstand it.

It can be said that the cabbage plants grown under control conditions without any treatment had higher levels of self-produced enzymatic antioxidants (catalase and peroxidase ($\Delta A \cdot min^{-1} \cdot g^{-1}$, FW)) in their tissues compared to those grown under compost (either plant residues or vermicompost) combined with gypsum and cobalt to tolerate salt stress. This is likely because cabbage plants have the ability to increase various scavenging mechanisms of free radicals (ROS) to alleviate the damage caused by salinity stress. Salinity stress disrupts the balance between free radical production and scavenging, resulting in oxidative damage to plant cells. Both types of compost can provide nutrients to cabbage plants, thereby helping them to tolerate salt stress. The addition of compost significantly reduced oxidative stress damage in cabbage by reducing the production of activated oxygen species and lipid peroxidation. In other words, the application of vermicompost and plant residues compost might reduce the accumulation of free radicals in compost-treated cabbage plants compared to untreated plants.

The cabbage plants treated with gypsum and cobalt had lower levels of enzymatic antioxidants (catalase and peroxidase ($\Delta A \cdot min^{-1} \cdot g^{-1}$, FW)) compared to those grown without these treatments. The decrease in enzymatic antioxidants in gypsum-treated plants can be attributed to the role of gypsum in increasing soil aggregates and leaching salt, which reduces the need for cabbage plants to produce more catalase and peroxidase. On the other hand, cobalt plays a vital role in boosting plant immunity and scavenging free radicals (ROS) in the chloroplast of cabbage plants, reducing the need for more catalase and peroxidase production. Therefore, it can be concluded that cobalt treatment alleviated the cabbage plant's self-production of catalase and peroxidase. These findings are consistent with previous studies by [9] [10] [11] [12] [13] [15] [32] [33]; and [34].

Finally, it can be said that the studied materials, namely vermicompost, agricultural gypsum, and cobalt, collectively contribute to mitigating salinity stress through several mechanisms. Vermicompost, rich in beneficial soil microbes and essential nutrients, enhances soil fertility, promoting improved plant growth and nutrient absorption. Agricultural gypsum acts by increasing soluble calcium in the soil, displacing adsorbed sodium, thereby mitigating dispersion effects and enhancing soil structure in saline conditions. Cobalt, recognized as an essential element for higher plants, plays a pivotal role in enhancing plant tolerance to salinity conditions. Its exogenous application reflects positively on growth performance, reducing the harmful effects of salinity stress. The combination of vermicompost, gypsum, and cobalt synergistically addresses various aspects of salinity stress, offering a comprehensive and effective approach to improving the resilience of cabbage plants in saline soils.

5. Conclusion

This study underscores the significant role of integrated treatments, specifically the combined use of vermicompost, agricultural gypsum, and cobalt, in mitigating the detrimental effects of soil salinity on cabbage plants. The findings highlight the positive impact of vermicompost on various growth and quality parameters, with cabbage plants treated with agricultural gypsum also showing improved performance. Furthermore, the application of cobalt, now recognized as an essential element for higher plants, demonstrated substantial benefits in terms of enhanced growth, yield, and quality. The study emphasizes the potential of these interventions in alleviating the challenges posed by soil salinity, offering valuable insights for farmers and policymakers seeking to boost agricultural productivity in salinity-affected regions. Moving forward, future research should delve into the long-term effects of these treatments on soil health and the sustainability of crops, providing a more comprehensive understanding of their implications.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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