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Strategies for Soil Rehabilitation and Yield Improvement under Saline Irrigation Water Conditions: The Role of Combining Soil amendments and Compost Tea

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Irrigation water salinity has led to significant soil degradation and reduced agricultural yields. This research aimed to identify effective strategies to alleviate these impacts by reducing soil degradation. A field experiment was conducted on maize, utilizing phosphogypsum, vermicompost, algae extract, and compost tea as treatments. The experiment followed a split-plot design with three replications. Appling vermicompost, biofertilizer (algae extract), and phosphogypsum, alone or in combination with compost tea, resulted in a moderate increase in soil organic carbon and cation exchange capacity. More notably, these treatments significantly enhanced the 100-grain weight, straw yield, and grain yield of maize. Additionally, soil bulk density decreased across treatments. The most effective treatment involved the use of a combination of half doses of vermicompost, phosphogypsum, and algae extract with compost tea, which significantly reduced soil electrical conductivity (EC), exchangeable sodium percentage (ESP), and bulk density (BD). Furthermore, this treatment improved soil porosity, soil penetration resistance (SPRa), and basic soil infiltration rate (IR). The findings suggest that the integration of organic amendments with compost tea in saline irrigation conditions positively impacts both soil quality and maize yield, offering a promising approach to managing saline irrigation in agricultural systems.

Keywords: Saline water, Phosphogypsum, Vermicompost, Maize yield, Compost tea and Algae extract, Soil properties.

1. Introduction

The sustainability of water resources is a critical issue for fulfilling the rising water demands of various competitive sectors including agriculture (Ingrao et al., 2023). Saline water irrigation has been widely employed to support agricultural productivity, compensate for the lack of freshwater resources, and guarantee the continuous growth of agricultural output, which in turn contributes to economic revenue and food security to satisfy the demands of an ever-growing population (Ingrao et al., 2023). Li et al., (2019) showed that a 1% increase in irrigation water salinity caused plants to grow shorter, lose weight and freshness, and produce less maize (between 0.4% and 3.3% less). One of the most popular cereals, maize is regarded as a crop that can withstand moderate salt (ref). Soil salinity needs to be managed at a concentration below which it could impact yield in to prevent yield loss (Tarolli et al., 2024).

Long-term water salinity exposure of the crop growth without facing can lead to increasing salts in the soil specific ion toxicity, effects on the soil physical quality, hormonal and nutritional imbalance, differences between average crop output quantitatively and qualitatively, cannot avoid causing adverse off-site effects due to the drainage water it generates and decreased water potential (Shrivastava and Kumar, 2015). Reliance on the use and reuse of saline waters will require careful planning, more complex management practices, minimizing the adverse environmental impacts, and stringent monitoring procedures, than when good water quality is used and innovation and appropriate technical methods (Yalin et al., 2023). It is not advisable to use low-quality irrigation water without the necessary

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additions since it can make the soil more saline. To prevent excessive soil salinization for crop production, specific management procedures must be implemented while using saline waters for irrigation (Malakar et al., 2019). The results of the study showed that after years of irrigation with salty water, the amount of salt that has accumulated in the soil grows linearly. The impact of saline water irrigation on soil permeability is mostly related to the effects of salt and ion content in the irrigation water (Wang et al., 2023). Vermicompost is an organic fertilizer produced through the decomposition of organic matter by earthworms. This process, known as vermiculture, transforms biodegradable waste into nutrient-rich compost, which enhances soil structure and fertility. Vermicompost contains essential nutrients such as nitrogen, phosphorus, and potassium, along with trace elements, enzymes, and beneficial microorganisms. It improves soil aeration, water retention, and microbial activity, making it highly effective in promoting plant growth and yield. Additionally, vermicompost enhances the availability of nutrients to plants and helps suppress soil-borne diseases, making it a sustainable and eco-friendly option for agricultural and horticultural practices (Ding et al., 2021).

Biofertilizers, such as algae extract, are natural products derived from algae that promote plant growth by enhancing nutrient availability and soil health. Algae extracts contain a wide range of nutrients, including essential minerals, amino acids, vitamins, and growth-promoting hormones like cytokinins, auxins, and gibberellins (Esraa et al., 2022). These components help stimulate root growth, improve nutrient uptake, and increase the plant's resistance to environmental stressors such as salinity, drought, and disease. Additionally, algae extract boosts soil microbial activity, improving soil structure and fertility. Its eco-friendly nature and ability to enhance crop yield make it an attractive solution for sustainable agriculture. Phosphogypsum is a byproduct of the phosphate fertilizer industry, primarily composed of calcium sulfate. It is widely used as a soil amendment to improve soil structure, especially in saline or sodic soils. Phosphogypsum helps to reduce soil salinity by displacing sodium ions and enhancing the leaching of salts, which improves water infiltration and root growth. It also provides calcium and sulfur, essential nutrients that support plant development and improve crop yield. By enhancing soil physical and chemical properties, phosphogypsum is particularly beneficial in arid and semi-arid regions, contributing to more sustainable agricultural practices under challenging soil conditions (Mahmoud et al., 2023).

Compost tea, a liquid extract derived from steeping compost in water, has gained increasing attention as an organic amendment with substantial benefits for soil health and plant growth (Ramírez-Gottfried et al., 2023), it is rich in beneficial microorganisms, nutrients, and growth-stimulating compounds, making it a sustainable option for enhancing soil fertility and plant resilience under various stress conditions, including salinity. The application of compost tea can improve the soil's biological activity by introducing beneficial microbes, which aid in nutrient cycling, suppress harmful pathogens, and improve soil structure (Bali et al., 2021). Additionally, compost tea helps plants to better absorb nutrients, thereby promoting stronger root systems and healthier plant development. Its use in agriculture not only boosts yield but also supports environmental sustainability by reducing the need for chemical fertilizers and pesticides (Srivastava et al., 2016). In saline irrigation conditions, compost tea is particularly advantageous due to its ability to improve soil conditions and enhance the tolerance of crops like maize to saline stress (Srivastava et al., 2016). A negative correlation was observed between soil salinity and soil organic matter according to Hassani et al. (2024). However, the integrated application of different amendments including compost tea has received less attention. The main objective of the study Synergistic Effects of Soil Amendments on Soil Properties and Maize Yield Under Saline Irrigation Conditions is to identify and evaluate effective strategies for mitigating the adverse effects of irrigation water salinity on soil quality and agricultural yields. Specifically, the research focuses on enhancing irrigation efficiency and reducing soil degradation by applying various soil amendments—phosphogypsum, vermicompost, algae extract, and compost tea—either alone or in combination. The study aims to determine how these treatments impact soil properties, such as organic carbon, cation exchange capacity, bulk density, electrical conductivity, and soil structure, as well as maize yield components like grain weight, straw yield, and overall grain yield**.**

2. Materials and Methods

Two field experiments were carried out in Kafr El Sheikh, Egypt, during the summer growth seasons of 2021 and 2022 to examine the effects on soil properties and maize crop productivity under saline irrigation water conditions of applying soil amendments (vermicompost (VC), alga extract, and phosphogypsum) with and without compost tea. The experimental design was arranged in a split-plot design with three replicates. The main plots were occupied by soil amendments, T1: check treatment, T2: alga extract (3kg fed^{-1}), T3: VC vermicompost (4 ton fed^{-1}), and T4: (C), phosphogypsum (2ton fed^{-1}). T5: 1/2(T2+T3), T6: 1/2(T2+T4), T7:1/2(T3 +T4), T8: 1/2(T2+T3 +T4). The use of algae extract as a soil amendment has been extensively documented for its ability to enhance soil fertility and plant growth, especially under stress conditions like salinity. Algae such as Chlorella vulgaris and Spirulina platensis release bioactive compounds, including phytohormones, amino acids, and polysaccharides, which improve soil structure, increase organic matter content, and enhance the availability of essential nutrients like nitrogen and phosphorus. These algae have also been shown to fix nitrogen, reduce soil salinity, and promote soil microbial activity, all of which contribute to improved crop productivity in saline environments. Phosphogypsum is a by-product of the phosphoric acid production process, primarily consisting of calcium sulfate. It has been widely used as a soil amendment to improve soil structure, fertility, and water infiltration, particularly in saline and sodic soils. Phosphogypsum is valued for its ability to supply calcium and sulfur to the soil, which are essential nutrients for plant growth. Calcium helps displace sodium ions on soil particles, which reduces soil salinity and sodicity, improving soil structure, permeability, and root penetration. In saline conditions, phosphogypsum works by providing a source of calcium that replaces sodium ions in the soil profile. This exchange reduces the amount of sodium, lowering the soil's exchangeable sodium percentage (ESP) and enhancing soil aggregation and porosity. As a result, water infiltration improves, and plants are better able to access nutrients and water. Phosphogypsum also increases sulfur availability, which is vital for protein synthesis and overall plant growth. Furthermore, its application has been shown to increase crop yield, particularly in salt-affected soils. Amount and Application of Compost Tea and Algae Extract

Compost tea was applied as a ground addition at a rate of 20 liters per fed. and was applied four times during the growing season: at sowing, 30 days after sowing (DAS), 60 DAS, and 90 DAS. Compost tea was prepared by steeping 10 kg of mature compost in 100 L of water for 48 hours, followed by filtration. Algae extract (3 kg fed^{-1}) was applied as a soil drench at sowing and 45 DAS to enhance nutrient availability and improve plant resilience to saline stress.

2.1 Sources of Materials

Phosphogypsum was sourced from the Soil Improvement Research Station at Sakha, Egypt. It is a by-product of phosphoric acid production, primarily consisting of calcium sulfate. Vermicompost was obtained from a local organic fertilizer supplier and produced through the decomposition of rice straw and animal manure using Eisenia fetida earthworms. Algae extract was procured from a certified biofertilizer supplier and primarily consisted of Chlorella vulgaris and Spirulina platensis species. Compost tea was prepared on-site using mature compost derived from organic farm waste, rich in microbial populations and nutrients.

Chemical and Microbial Analysis of Compost Tea

Compost tea was subjected to chemical and microbial analyses to evaluate its nutrient content and microbial load. Chemical analysis showed the tea contained 0.8% nitrogen, 0.2% phosphorus, 0.4% potassium, and trace amounts of micronutrients such as iron, copper, and zinc. Microbial analysis revealed that compost tea had a diverse population of beneficial microorganisms, including Bacillus spp., Pseudomonas spp., and various fungi that aid in nutrient cycling and pathogen suppression. The total microbial count was 1.5 × 10^8 CFU/ml. The subplots were devoted to with and without compost tea. Therefore, the experiment units were 48 plots (8 soil amendments X 2- compost tea X 3 rep.) where the area of each plot was 42 m^2 (6X 7m). Maize (cv single 10) was sown on 20th May, 2021. The maize plants were harvested after 160 days after sowing (DAS). All the recommended agronomic practices were applied. N-fertilizer was applied to maize as urea (46.5% N) at a rate of 168 kg fed^{-1} in two equal doses at 21 and 55 DAS, respectively. The recommended dose of 150 Kg P_2O_5 fed^{-1} as mono phosphate (15.5% P_2O_5) and 50 Kg K_2O fed^{-1} as potassium sulfate (48% K_2O) were applied before planting. 100-grain weight, grain, straw and biological yield were determined at the harvesting stage. Before initiating the tests and following the harvest of the maize crop for all treatments, soil samples were collected from three distinct depths (0–20 cm, 20–40 cm, and 40–60 cm) for a series of physical and chemical analyses. Saturated soil paste extract, exchangeable sodium percentage (ESP), and cation exchange capacity (CEC) were used to measure salinity according to Page et al (1982). The Walkley and Black method was utilized to ascertain the content of organic matter (OM) according to Black (1965). The bulk density and total porosity of the various soil layers for each treatment were measured using the core sampling technique as described by Campbell (1994). Using the pipette method, the soil's particle size distribution was determined according to Kettler et al (2001). Infiltration rate was determined using double cylinder infiltrometer as described by Garcia (1978). Soil penetration resistance is directly measured with a penetrometer (ref). Using the pressure membrane method, field capacity (FC) and permanent wilting point (PWP) were calculated at 0.33 and 15 bars Klute (1986).

Phosphogypsum (PG) is an industrial by-product created by wet-acid generation of phosphoric acid from rock phosphate at Abu-Zaable district (El-Sharkia governorate). PG was obtained from Soil Improvement at Sakha Station. PG is an acidic waste material (pH= 3.8) and its main components are calcium sulfate of 93.0%, oxides of calcium of 19.6%, silicon of 10.7%, aluminum of 1.15% and iron of 3.0% and some impurities such as P2O5 (0.5-1.4%), F, sodium silicate and organic substances. While the VC was made from rice straw and animal wastes with earthworm species *Eiseniafetida* and *Dendrobaenaveneta* (Joshi et al 2014).

2.2. Statistical Analyses

The experimental data were analyzed using the Statistical Package for the Social Sciences (SPSS) software, version 29.0.2. A two-way analysis of variance (ANOVA) was conducted to assess the effects of the soil amendments and compost tea on soil properties and maize yield. The split-plot design allowed for interaction effects between soil amendment types and the presence or absence of compost tea. Significant differences between treatment means were determined using the Least

Phosphogypsum was applied according to (Rashed et al.2022). Phosphogypsum and VC were thoroughly mixed with the surface soil layer (0-30 cm) before cultivation, and then it was ploughed twice in two ways using chisel plough. While maintaining the drainage system in the soil. Some physical and chemical properties of the experimental soil are shown in Table (1). The chemical composition of VC was listed in Table (2). Some chemical composition of irrigation water as show in table 2. The meteorological data during the two growing seasons are presented in Table (3).

Significant Difference (LSD) test at a 5% probability level ($p < 0.05$). Correlation analysis was also performed to explore relationships between soil properties and maize yield components. The statistical analysis was aligned with the goal of evaluating the combined effects of organic and chemical amendments under saline irrigation, providing insights into the synergistic impact on soil health and crop productivity.

TABLE 1. Average values of some physicochemical properties of the experimental site during the two growing seasons

Soil Chemical Properties

Soil depth	pH	EC (dSm^{-1})	Cations meq / L				Anions meq / L				SAR	ESP (%)
			Na^+	K^+	Ca^{++}	Mg^{++}	$CO_3^=$	HCO_3^-	Cl^-	$SO_4^=$		
0-20	7.98	3.12	22.2	0.31	7.39	1.3	0	6.11	14.67	10.42	11.12	12.25
20-40	7.98	3.21	23.08	0.36	7.4	1.26	0	6.11	15.59	10.4	11.37	12.49
40-60	8.01	3.45	25.61	0.9	7.94	1.26	0	6.11	17.35	10.99	11.75	12.84
mean		3.26	24.33	0.33	7.81	1.27	0	6.11	17.03	10.6	11.41	12.53

Soil depth (cm)	CEC ($cmole\ kg^{-1}$)	OM ($g\ kg^{-1}$)	$CaCO_3$ (gkg^{-1})	N ($mgkg^{-1}$)	P ($cmole\ kg^{-1}$)	K ($g\ kg^{-1}$)
0-20	38.93	1.36	2.15	27.8	8.5	260
20-40	37.28	1.24	2.31	27.1	8.3	256
40-60	36.81	1.09	2.25	23.5	7.5	241
mean	37.67	1.23	2.24	26.13	8.1	252.33

ESP is calculated

Soil Physical Properties

Soil depth	Soil moisture characteristics					Particle size distribution (%)			Soil texture
	F.C. (%)	W.P. (%)	A.W. (%)	BD (kg m^{-3})	Total porosity (%)	Sand	Silt	Clay	
0-20	42.5	22.1	20.4	1.35	49.06	11.90	33.90	54.20	clay
20-40	40.7	20.3	20.4	1.38	47.93	12.35	34.40	53.25	clay
40-60	37.6	19.0	18.6	1.44	45.66	11.60	34.20	54.20	clay
mean	40.27	20.47	19.80	1.39	47.55	11.98	34.17	53.88	clay

F.C.: Field Capacity**; W.P.:** Wilting Point; **A.W.**: Available Water; **BD**: Bulk Density

TABLE 2. Some chemical composition of Vermicompost (VC)

EC dSm^{-1}	pH	moisture	Organic carbon	N	P	K	Na	Ca	Mg	Cu	Fe	Zn
		%	%		%			Meq$(100g)^{-1}$			mg kg^{-1}	
3.11	7.55	25	12	1.1	0.16	0.45	0.08	14.1	8.15	2.1	1.35	9.48

TABLE 2.1. Some chemical composition of irrigation water

pH	ECe	Cations meq / L				Anions meq / L				SAR
		Na^+	K^+	Ca^{++}	Mg^{++}	$CO_3^=$	HCO_3^-	Cl^-	$SO4^=$	
7.55	2.5	16.3	0.8	6.3	2.1	0.0	2.50	13.0	9.8	7.96

TABLE 3: Climatological data of Sakha Agricultural Research Station during the two maize growing seasons 2021 and 2022.

Season	Month	Mean temperature (C°)	Relative humidity (%)	Wind velocity km day^{-1}	Evaporation (cm day^{-1})
2021	May	28.35	59.60	97.8	8.94
	jun	28.90	65.20	111.0	8.92
	Jul	32.40	69.90	95.9	9.05
	Aug.	33.10	67.70	82.9	7.60
	Sept.	29.15	66.90	96.7	7.42
2022	May	25.90	61.20	100.97	7.11
	juni	29.40	66.60	88.83	7.40
	Jul	29.20	71.10	104.7	7.93
	Aug.	31.20	73.65	105.0	7.50
	Sept.	29.50	69.40	96.7	6.20

3. Results and discussion

3.1 Soil chemical properties

In the present study, synergistic application of vermicompost, phosphogypsum and algae extract alone or with compost tea technology improved soil chemical properties, soil physical properties, plant growth, physiological traits, biochemical traits, and maize yield in comparison to their sole application during 2021 and 2022growing seasons. Regarding the interaction between irrigation water salinity and the combined treatments, all the plants subjected to the triple treatment (vermicompost + phosphogypsum + algae) with the irrigation saline water had the ability to overcome the deleterious effect of salt stress increment with a significant effect on in both growing seasons as compared with the control which either received saline water alone.

Likewise, combined treatments with compost tea were significantly reducing EC and ESP (%) more than amendments treated by the sole or with triple treatments. The increase in soil salinity due to irrigation with saline water was also reported by (Feng et al., 2017; Hassani et al., 2021; Zhang et al., 2024). The organic amendments (vermicompost) mitigate salt stress via a wide range of mechanisms, including the regulation of ionic homeostasis, antioxidant enzyme activities, and the reduction of oxidative damage (Ding et al., 2021). Furthermore, the addition of compost tea further enhanced the efficacy of organic amendments in mitigating salt stress. Compost tea is known for its high microbial activity, which plays a pivotal role in improving soil structure, enhancing nutrient availability, and reducing soil salinity (Ho et al., 2022). The microbial inoculants present in compost tea likely contributed to the breakdown of organic matter, improving soil aeration and water retention. These improvements in soil health create a more favourable environment for root development, allowing plants to access nutrients and water more efficiently, even under saline conditions. The synergistic effects of compost tea combined with vermicompost, phosphogypsum, and algae extract likely contributed to a reduction in the accumulation of harmful salts within the root zone, leading to improved plant growth and yield (El-Maghraby et al., 2024). Moreover, compost tea's ability to promote beneficial microbial populations in the soil can enhance plant resilience by stimulating systemic acquired resistance (SAR) pathways, helping plants cope with environmental stresses such as high salinity. This biological boost, combined with the physical and chemical improvements provided by organic amendments, highlights the importance of integrated soil management practices in saline irrigation systems. The findings of this study are consistent with previous research indicating that compost tea not only improves soil properties but also plays a critical role in promoting plant growth and resilience under stressful conditions (Köninger et al., 2021; Tarashkar et al., 2023). By drawing the related ions from the soil, the application of phosphogypsum, vermicompost, and algae reduced the salinity of the soil. By preserving high Ca/Na ratios, phosphogypsum application can stop soil dispersion, fostering clay flocculation and structural stability. These findings are supported by (Rashmi et al., 2024) who reported that the integration between phosphogypsum and organic amendments could improve the chemical properties of soil.

TABLE 4: Soil salinity (EC, dSm^{-1}) and exchangeable sodium percentage (ESP %) as affected by combination of soil amendments and compost tea during two growing.

Treatments		Summer 2021		Summer 2022	
		EC		ESP	
T1	without	3.80a	12.27a	3.85a	12.34a
	compost tea	3.73 d	12.17d	3.81b	12.28b
T2	without	3,76b	12.21b	3.81b	12.28b
	compost tea	3,71 e	12.14e	3.80c	12.27c
T3	without	3.74c	12.19c	3.81b	12.28b
	compost tea	3.65 f	12.06f	3.78d	12.24d
T4	without	3.59 g	11.98g	3.70e	12.13e
	compost tea	3.55i	11.92i	3.64g	12.05f
T5	without	3.58 h	11.96h	3.67f	12.09g
	compost tea	3.49j	11.83j	3.56i	11.93i
T6	without	3.55i	11.92i	3.61h	12.0h
	compost tea	3.45m	11.77m	3.48l	11.82l
T7	without	3.48k	11.82k	3.54j	11.90j
	compost tea	3.42n	11.73n	3,45n	11.77m
T8	without	3.46l	11.79l	3.50k	11.84k
	compost tea	3.30o	11.55o	3.28n	11.52n
SA		**	**	**	**
$LSD_{0.05}$		0.001	0.001	0.003	0.002
$LSD_{0.01}$		0.002	0.002	0.004	0.003
M		*	*	*	*
$LSD_{0.05}$		0.001	0.0008	0.001	0.001
$LSD_{0.01}$		0.003	0.001	0.002	0.002
SA x M		*	*	*	*
$LSD_{0.05}$		0.002	0.002	0.005	0.004
$LSD_{0.01}$		0.003	0.003	0.007	0.005

- T1: T2:

The content of OM in rhizosphere soil was affected ($p \leq 0.01$) by simple effect of T8 (1/2 (a+b+c) combined with compost tea and irrigation water salinity treatments (Fig. 1). Vermicompost and algae extract play a vital role in the cycle of organic matter and the availability of nutrients in the soil and regulate various ecological processes related to the growth of plants in the soil (Verrone et al., 2024). On the other hand, irrigation maize with saline water caused a significant decrease in soil organic matter content. Based on the results, in comparison with the control, the content of soil OM decreased at the irrigation water salinity. The reduction of soil organic matter in saline conditions can be attributed to the reduction of vegetation and the entry of plant material into the soil.

3.2. Soil physical properties

Applying soil amendments resulted in a considerable drop in the bulk density of the soil, as Table 5 illustrates. In comparison to the other treatments, the application of ½ (vermicompost + phosphogypsum + algal extract) combined with compost tea for the 2022 and 2023 growth seasons produced the lowest values (1.34 and 1.33 kg m-3). The application of soil amendments significantly increased the porosity of the soil, as demonstrated by the data in Table 5. Among the treatments tested, the application of 1/2 (vermicompost + phosphogypsum + algae extract) combined with compost tea for the 2021 and 2022 growing seasons produced the highest values (49.43 and 49.58%). Soil penetration resistance decreased significantly with the application of (vermicompost + phosphogypsum+ algae extract) combined with compost tea and recorded the lowest values with 1/2(vermicompost + phosphogypsum+ algae extract) combined with compost tea for the 2022 and 2023 growing seasons compared to the other treatments. These results are supported by the authors of (Amer et al., 2023), who stated that adding compost is acknowledged as a dependable method for restoring the physicochemical characteristics of soil and encouraging microbial activity in the soil, particularly in soils with low organic matter and poor structure. The soil basic infiltration rate exhibited a similar pattern, with the highest values found when compost tea and 1/2 (vermicompost + phosphogypsum + algal extract) were applied to the soil (Figure 2). These results may be attributed to the application of compost tea to saline–sodic soils, which enhances its infiltration rate according to (Srivastava et al., 2016). Organic ameliorators have many benefits for soil health as they enhance physical (soil porosity and bulk density) and chemical (EC and ESP) soil quality parameters (Ding et al., 2020).

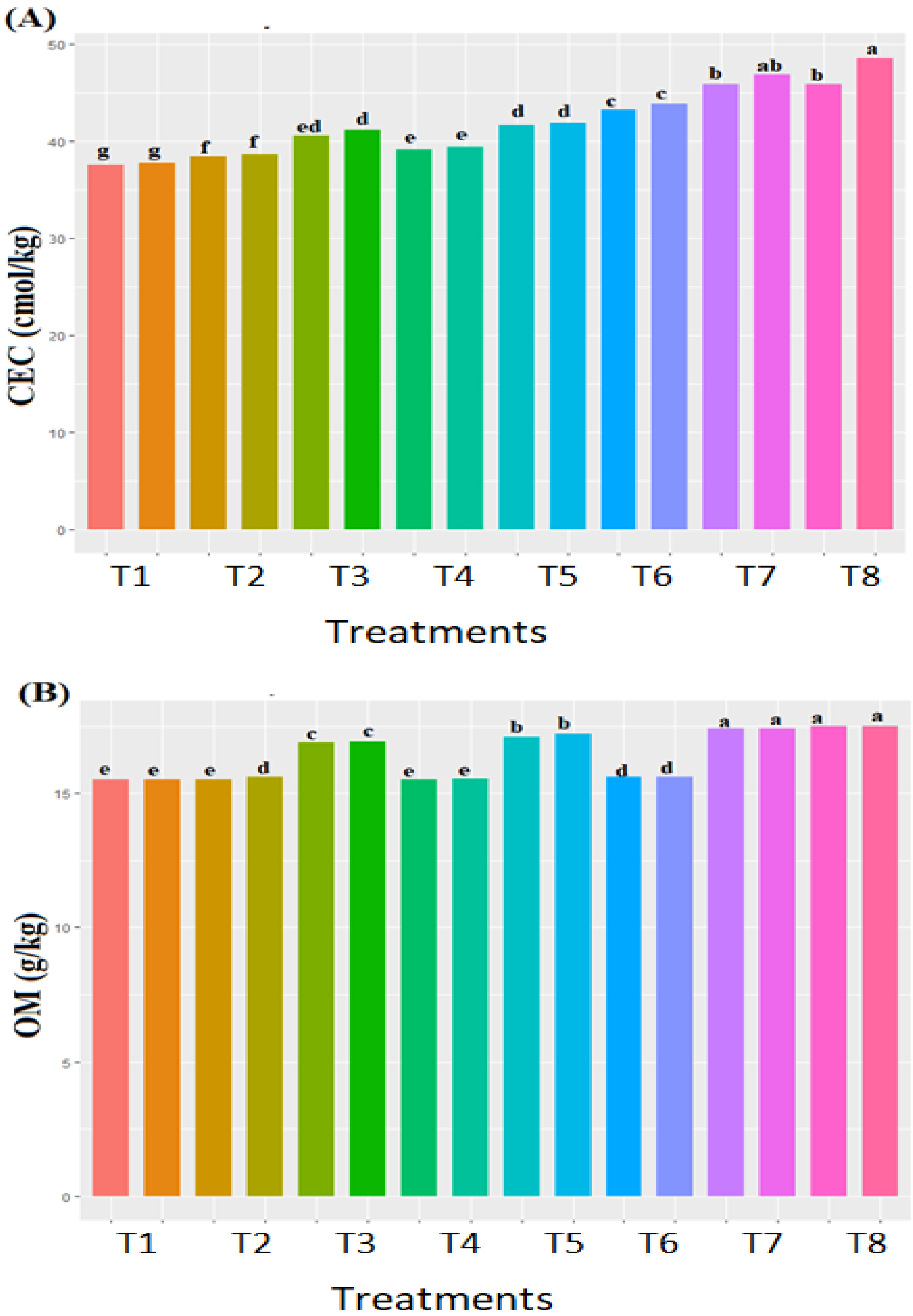

Fig. 1: Cation exchange capacity (CEC) (A) and Organic matter (OM (B)) as affected by combination of soil amendments and compost tea during two growing. T1: T2:

TABLE 5: Soil bulk density (kg m^{-3}) and soil porosity (%) as affected by as affected by combination of soil amendments and compost tea during two growing.

Treatments		Summer 2021		Summer2022	
		Bd	**Porosity**	**Bd**	**Porosity**
T1	**without**	1.41a	46.79g	1.406a	46.94g
	compost tea	1.41a	46.79g	1.406a	46.94g
T2	**without**	1.40b	47.17f	1.396b	47.32f
	compost tea	1.40b	47.17f	1.396b	47.32f
T3	**without**	1.37d	48.30d	1.366d	48.45d
	compost tea	1.37d	48.30d	1.366d	48.45d
T4	**without**	1.38c	47.92e	1.376c	48.08e
	compost tea	1.38c	47.92e	1.376c	48.08e
T5	**without**	1.36e	48.68c	1.356e	48.83c
	compost tea	1.36e	48.68c	1.356e	48.83c
T6	**without**	1.37d	48.30d	1.366d	48.45d
	compost tea	1.37d	48.30d	1,366d	48.45d
T7	**without**	1.35f	49.06b	1.346f	49.41b
	compost tea	1.35f	49.06b	1.346f	49.41b
T8	**without**	1.34g	49.43a	1.336g	49.58a
	compost tea	1.34g	49.43a	1.336g	49.58a
Soil amendments (SA)		**	**	**	**
$LSD_{0.05}$		0.003	0.004	0.002	0.003
$LSD_{0.01}$		0.006	0.005	0.003	0.005
Compost tea (M)		ns	ns	ns	ns
SA x M		ns	ns	ns	ns

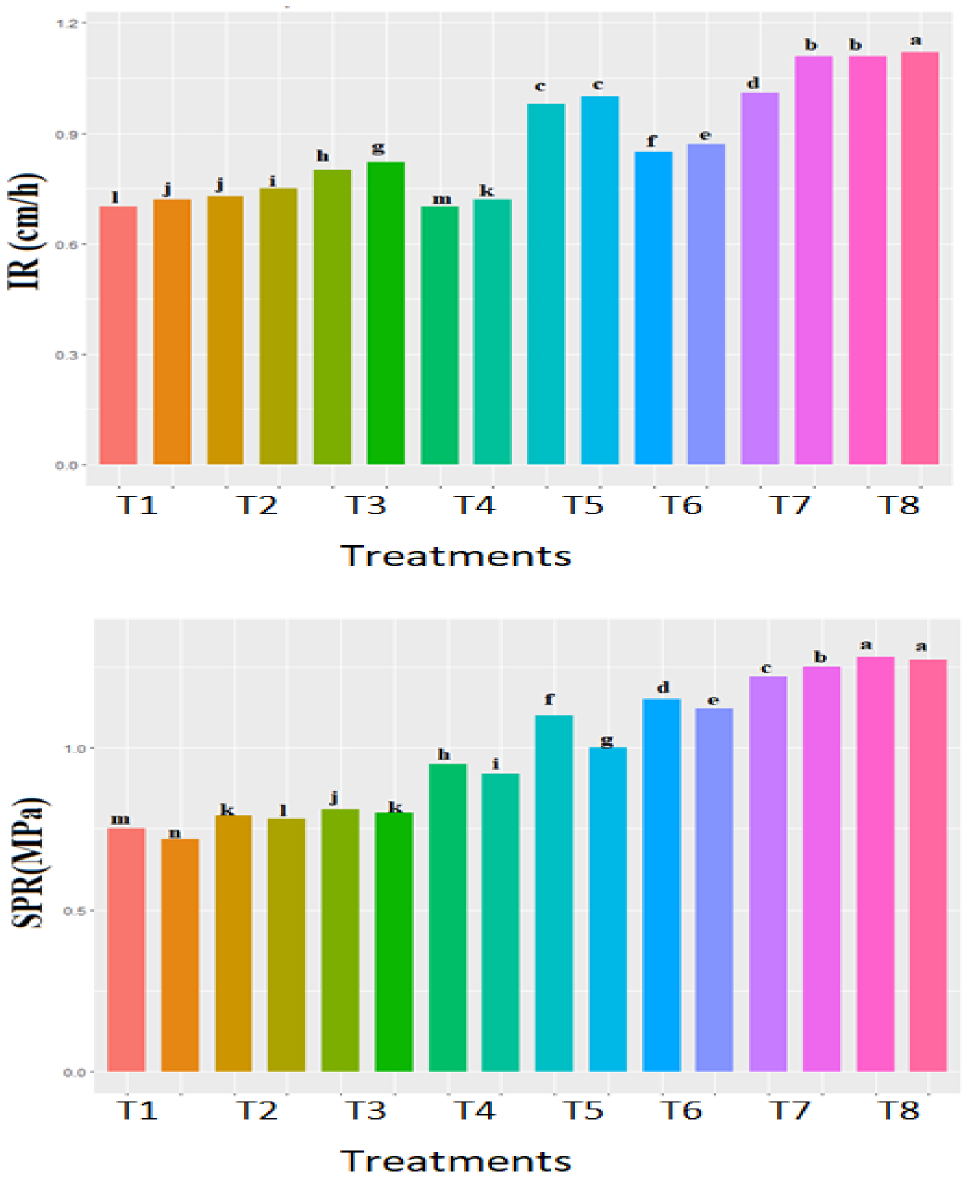

Fig. 2: Soil infiltration (IR) and soil penetration resistances (SPRa) as affected by combination of soil amendments and compost tea during two growing seasons. T1: T2:

3.3. Yield of maize

Table (6) showed that 100-grain weight was highly significant increased due to soil application and recorded highest values by T8. 100-grain weight was highly significant increased by compost tea and recorded highest values as compared without treatment.100-grain weight was highly significant increased due to the interaction between soil application and compost tea. Where recorded highest values (35.95 and 36.12g) for 1st and 2nd season, respectively. Grain yield of maize was highly significant increased by application of alga extract, phosphogypsum, vermicompost and recorded highest values by combinations between the treatments (T8). With regarded to compost tea treatment, grain yield of maize was positive significant increased as compared without treatment. Also, the same data showed that grain yield of maize was significant increased due to the interaction between the soil application and compost tea treatment, and recorded highest values (3170.0 and 3225.3kg/fed.) for 1st and 2nd seasons. Table (6) showed the straw yield took the previous trend. These findings might be connected to how vermicompost enhances plant growth as reported by (Blouin et al., 2019). Furthermore, the combination of all examined treatments resulted in a significant increase in maize grain and straw yields. These findings might be explained by the substantial and beneficial effects of phosphogypsum, vermicompost, and algae extract on the physical and chemical characteristics of the soil, which enhanced the plant's capacity to absorb nutrients and water, increasing the rate of metabolism and the amounts of chlorophyll and proline (Liu et al., 2022). When the maize plants were exposed to salinity during irrigation in 2021 and 2022, it also had a negative impact on yield and yield biomass. But in plants treated with soil supplements, such as VC, phosphogypsum, algal extract, and their combination with compost tea, this effect was reversed. Adding VC to agricultural soil in the form of organic amendments, phosphogypsum, and algal extract can improve soil nutrient cycling, boost crop yields, and increase the availability of N, P, and K (Mahmoud et al., 2023). Li et al., (2024) demonstrated that saline water irrigation raised the level of salt stress, which in turn caused a decrease in the yield of maize as well as the photosynthetic rate, transpiration rate, stomata conductance, and leaf water potential. Applying rodent compost and/or phosphogypsum boosted the 100-grain weight significantly, as Table 6 illustrates. For the 2022 and 2023 growing seasons, the application of compost + gypsum produced the greatest values of algal extract (69.62 and 69.73 g).

TABLE 6: 100-GW, grain and straw yield of Maize (kg fed.$^{-1}$) as affected by combination of soil amendments and compost tea during two growing.

Treatments		Summer 2021			Summer 2022		
		100-GW	Grain	Straw	100-GW	Grain	Straw
T1	**Without**	33.42n	2327.6m	2562.3o	33.46n	2352.7o	2596.3h
	Compost tea	33.79m	2412.3l	2660.7m	33.83m	2444.3n	2687.7gh
T2	**Without**	33.92l	2460.0k	2583.3n	33.97l	2490.0m	2612.3h
	Compost tea	34.17h	2615.3j	2755.3l	34.21h	2650.3l	2779.3fg
T3	**Without**	33.97jk	2758.6i	2816.67k	34.01jk	2788.7k	2845.7ef
	Compost tea	34.67e	2887.0f	2915.0h	34.72e	2926.0g	2935.0de
T4	**Without**	33.95k	2762.3i	2855.0j	33.99kl	2792.3k	2884.0de
	Compost tea	34.67e	2895.3e	2965.3f	34.71e	2934.3f	2985.3d
T5	**Without**	33.98ij	2762.3i	2916.7h	34.02j	2792.3j	2940.7de
	Compost tea	34.97d	2912.0d	3105.7e	35.01d	2954.0e	3122.7c
T6	**Without**	34.01i	2788.6h	2884.3i	34.05i	2828.7i	2903.3de
	Compost tea	35.27c	2925.0c	3247.0b	35.31c	2974.0c	3257.0ab
T7	**Without**	34.29g	2812.0g	2950.0g	34.33g	2855.3h	2966.0d
	Compost tea	35.82b	2980.0b	3320.0a	35.87b	3033.3b	3326.0a
T8	**Without**	34.59f	2915.0 d	3145.7d	34.64f	2963.0d	3156.7bc
	Compost tea	35.95a	3170.0a	3208.3c	36.12a	3225.3a	3212.3bc
SA		**	**	**	**	**	**
$LSD_{0.05}$		0.023	3.45	8.09	0.020	3.45	8.09
$LSD_{0.01}$		0.033	4.79	11.23	0.029	4.79	11.23
M		**	**	**	**	**	**
$LSD_{0.05}$		0.009	1.37	3.74	0.007	1.38	3.73
$LSD_{0.01}$		0.012	1.89	5.12	0.01	1.89	5.14
SA x M		**	**	**	**	**	**
$LSD_{0.05}$		0.026	3.87	10.57	0.021	3.89	10.58
$LSD_{0.01}$		0.036	5.35	14.55	0.030	5.36	14.56

T1: control, T2: (A), alga extract (3 kg fed^{-1}), T3: (B) vermicompost (4 ton fed^{-1}), T4: (C), phosphogypsum (2 ton fed^{-1}), T5: 1/2(A+B), T6: 1/2(A+C), T7:1/2(B +C), T8: 1/2(A+B+C).

Table (7) showed that bio yield of maize was highly significant increased by application of algae, PG, VC and recorded highest values by treatment of (T8). Further, the same data pointed out that bio yield of was significantly increased with treatment of compost tea as compared without treatment. The data showed that bio yield of maize was highly significant increased due to the interaction between the soil application and compost tea treatment and recorded highest values due to the interaction between T8 and compost tea. Table (7) showed that harvest index (%) of maize was highly significant increased by application of algae, PG, VC and recorded highest values by treatment of(T8). In addition, the same data pointed out that harvest index (%) of maize was significantly increased with treatment of compost tea as compared without treatment. The data showed that harvest index (%) of maize was highly significant increased due to the interaction between the soil application and compost tea treatment and recorded highest values due to the interaction between T8 and compost tea.

TABLE 7: Bio-yield of Maize (kg fed^{-1})and harvest index (%)as affected by soil conditioners ,compost tea and their the interaction during two growing.

Treatments		**Summer 2021**		**Summer2022**	
		Bio-yield (kg/fed.)	**HI (%)**	**Bio-yield (kg/fed.)**	**HI (%)**
T1	**Without**	4890.0o	47.6i	4949.0o	47.54l
	Compost tea	5073.0m	47.55i	5132.0m	47.62kl
T2	**Without**	5043.3n	48.77de	5102.3n	48.80g
	Compost tea	5370.6l	48.69ef	5429.6l	48.81g
T3	**Without**	5575.3k	49.48b	5634.3k	49.49c
	Compost tea	5802.0g	49.76a	5861.0g	49.92b
T4	**Without**	5617.3j	49.17c	5676.3j	49.19e
	Compost tea	5860.6f	49.40b	5919.6f	49.56c
T5	**Without**	5679.0i	48.64f	5738.0i	48.75g
	Compost tea	6017.6e	48.39g	6076.6e	48.61h
T6	**Without**	5673.0i	49.15c	5732.0i	49.35d
	Compost tea	6172.0c	47.39j	6231.0c	47.73j
T7	**Without**	5762.3h	48.80d	5821.3h	49.05f
	Compost tea	6300.0b	47.3j	6354.3b	47.70jk
T8	**Without**	6060.6d	48.09h	6119.6d	48.41i
	Compost tea	6378.6a	49.07a	6437.6a	50.1a
SA		**	**	**	**
$LSD_{0.05}$		9.04	0.072	9.05	0.073
$LSD_{0.01}$		12.56	0.100	12.55	0.100
M		**	**	**	**
$LSD_{0.05}$		4.03	0.032	4.04	0.033
$LSD_{0.01}$		5.62	0.045	5.56	0.045
SA x M		**	**	**	**
$LSD_{0.05}$		11.41	0.092	11.40	0.091
$LSD_{0.01}$		15.73	0.127	15.74	0.127

T1:control, T2: (A), alga extract (3 kgfed.$^{-1}$), T3: (B)vermicompost (4 tonfed.$^{-1}$), T4: (C), phosphogypsum (2 tonfed.$^{-1}$), T5: 1/2(A+B), T6: 1/2(A+C), T7:1/2(B +C), T8: 1/2(A+B+C).

4. **Conclusions**

The findings of this study underscore the substantial benefits of adopting a synergistic soil amendment strategy, particularly in saline irrigation conditions. The combined application of vermicompost, phosphogypsum, algae extract, and compost tea resulted in marked improvements in soil health, reflected by reduced electrical conductivity (EC) and exchangeable sodium percentage (ESP). These changes in soil properties were strongly associated with enhanced plant growth, physiological performance, and biochemical traits, which together contributed to significantly higher maize yields across both the 2021 and 2022 growing seasons. Notably, compost tea emerged as a critical component, enhancing microbial activity, increasing nutrient availability, and mitigating the adverse effects of soil salinity, thereby amplifying the effectiveness of other organic amendments. This integrated approach proved far superior to the use of individual amendments, highlighting the importance of combining biological, chemical, and organic treatments for optimal results. In light of the growing challenges posed by saline water irrigation on agricultural productivity, the findings of this study provide strong support for adopting organic amendments like compost tea as part of a sustainable soil management strategy. These treatments not only enhance soil resilience but also bolster plant tolerance to salinity, offering farmers a viable solution to counter soil degradation and maintain productivity under harsh conditions. While further research is needed to explore the long-term effects of these treatments across different crops and environments, this study clearly demonstrates the powerful potential of combining organic and biological amendments to improve crop performance and sustainability in saline environments.

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References

Amer, M.M., Aboelsoud, H.M., Sakher, E.M. and 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.

Bali, R., Pineault, J., Chagnon, P.L. and Hijri, M., 2021. Fresh Compost Tea Application Does Not Change Rhizosphere Soil Bacterial Community Structure, and Has No Effects on Soybean Growth or Yield. Plants (Basel), 10(8).

Black CA. Methods of soil analysis. Amer. Soc. Agro. Inc., Madison, Wisconsin, U.S.A; 1965.

Blouin, M., Barrere, J., Meyer, N., Lartigue, S., Barot, S., Mathiew, J., 2019. Vermicompost significantly affects plant growth. A meta-analysis. Agronomy for Sustainable Development, 39(4): 34.

Campbell DJ. Determination and use of bulk density in relation to soil compaction. In Soane and Ouwerk (Eds) Soil Compaction in Crop Production Elsever, London and Amsterdam; 1994.

Ding, Z., Kheir, A.M.S., Ali, M.G.M., Ali, O.A.M., Abdelaal, A.I.N., Lin, X., Zhou, Z., Wang, B., Liu, B., He, Z., 2020. The integrated effect of salinity, organic amendments, phosphorus fertilizers, and deficit irrigation on soil properties, phosphorus fractionation and wheat productivity. Scientific Reports, 10(1): 2736.

Ding, Z., Kheir, A.M.S., Ali, O.M.A., Hafez, E.M., Elshamey, E., Zhou, Z., Wange, B., Lin, X., Ge, Y., Fahmy, A.E., Seleiman, M.F.., 2021. A vermicompost and deep tillage system to improve saline-sodic soil quality and wheat productivity. Journal of Environmental Management, 277: 111388.

El-Maghraby, F.M., Shaker, E.M., Elbagory, M., Omara, A.E. and Khalifa, T.H., 2024. The Synergistic Impact of Arbuscular Mycorrhizal Fungi and Compost Tea to Enhance Bacterial Community and Improve Crop Productivity under Saline-Sodic Condition. Plants (Basel), 13(5).

Esraa E. Ammar, Ahmed A.A. Aioub, Ahmed E. Elesawy, Ali M. Karkour, Moustafa S. Mouhamed, Aliaa A. Amer, Nouran A. EL-Shershaby,Algae as Bio-fertilizers: Between current situation and future prospective, Saudi Journal of Biological Sciences, Volume 29, Issue 5, 2022, Pages 3083-3096.

Feng, G., Zhang, Z., Wan, C., Lu, P. and Bakour, A., 2017. Effects of saline water irrigation on soil salinity and yield of summer maize (Zea mays L.) in subsurface drainage system. Agricultural Water Management, 193: 205-213.

Garcia G. 1978. Soil water Engineering Laboratory Manual. Colorado State Univ. Dept. of Agric. and Chemical Engineering. Fortcollins, Colorado;

Hassani, A., Azapagic, A. and Shokri, N., 2021. Global predictions of primary soil salinization under changing climate in the 21st century. Nature Communications, 12(1): 6663.

Hassani, A., Smith, P. and Shokri, N., 2024. Negative correlation between soil salinity and soil organic carbon variability. Proceedings of the National Academy of Sciences, 121(18): e2317332121.

Ho, T.T.K., Tung, T.V., Hai, L., Ngoc, N., Xuan, B., 2022. Compost to improve sustainable soil cultivation and crop productivity. Case Studies in Chemical and Environmental Engineering, 6: 100211.

Ingrao, C., Strippoli, R., Lagioia, G. and Huisingh, D., 2023. Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks. Heliyon, 9(8): e18507.

Kettler TA, Doran JW, Gilbert TL. 2001. Simplified method for soil particlesize determination to accompany soil-quality analyses. Soil Science Society of America Journal.;65:849–852.

Klute A. 1986. Methods of Soil Analysis, Part 1, Physical and Mineralogical properties, Amer., Society, Agronomy, Monograph 9, 2nded. Madison, Wisc., USA;.

Köninger, J., Lugato, E., Panagos, P., Briones, M.G.I., 2021. Manure management and soil biodiversity: Towards more sustainable food systems in the EU. Agricultural Systems, 194: 103251.

Li, J., Chen, J., Jin, J., Wang, S. and Du, B., 2019. Effects of Irrigation Water Salinity on Maize (Zea may L.) Emergence, Growth, Yield, Quality, and Soil Salt. Water, 11(10): 2095.

Li, J., Wu, Y., Li, J., Feng, X., Ren, Y., Guo, K., Liu, X., 2024. Heterogeneous saline water irrigation improves stomatal and nonstomatal restrictions to decrease yield reduction threshold in cherry tomato. Scientia Horticulturae, 326: 112788.

Liu, X., Zhange,J., Wang, Q., Change, T., Shaghaleh, H., Hamoud, Y.A., 2022. Improvement of Photosynthesis by Biochar and Vermicompost to Enhance Tomato (Solanum lycopersicum L.) Yield under Greenhouse Conditions. Plants (Basel), 11(23).

Mahmoud, E., Ghoneim, A., Seleem, M., Zuhair, R., 2023. Phosphogypsum and poultry manure enhance diversity of soil fauna, soil fertility, and barley (Hordeum aestivum L.) grown in calcareous soils. Sci Rep, 13(1): 9944.

Malakar, A., Snow, D.D. and Ray, C., 2019. Irrigation Water Quality—A Contemporary Perspective. Water, 11(7): 1482.

Page AL, Miller H, Keeney DR. 1982. Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. 2nd Edition, Agronomy Monograph.; No. 9, ASA, CSSA, and SSSA, Madison.

Ramírez-Gottfried, R., Rangel, P., Carrillo, M.G., Garcia, A.B., 2023. Compost Tea as Organic Fertilizer and Plant Disease Control: Bibliometric Analysis. Agronomy, 13(9): 2340.

Rashed S. H., E. G. Abo-Elela and M. M. Amer (2022). Improving and Sustaining some Soil Properties by Application of some Soil Amendments and N- Fertilizer and its Effect on Productivity of Wheat and Rice Crops under Salt-Affected Soils.AJSSPN, 8(2): 1-12, 2022.

Rashmi, I., Meena, B.P., Rajendiran, S., Jayaraman, S., Joshy, C.G., Ali, S., Mina, B.L., Kumar, K., Kumar, A., 2024. Can gypsum and organic amendments achieve sustainability, productivity and maintain soil health under soybean-mustard cropping in sodic soils of western India. Soil and Tillage Research, 240: 106075.

Shrivastava, P. and Kumar, R., 2015. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi J Biol Sci, 22(2): 123-31.

Srivastava, P.K., Gupta, M., Shikha, Singh, N. and Tewari, S.K., 2016. Amelioration of Sodic Soil for Wheat Cultivation Using Bioaugmented Organic Soil Amendment. Land Degradation & Development, 27(4): 1245-1254.

Tarashkar, M., Matloobi, M., Qureshi, S. and Rahimi, A., 2023. Assessing the growth-stimulating effect of tea waste compost in urban agriculture while identifying the benefits of household waste carbon dioxide. Ecological Indicators, 151: 110292.

Tarolli, P., Luo, J., Park, E., Barcaccia, G. and Masin, R., 2024. Soil salinization in agriculture: Mitigation and adaptation strategies combining nature-based solutions and bioengineering. iScience, 27(2): 108830.

Verrone, V., Gupta, A., Laloo, A.E., Dubey, R.K., Abdul Hamid, N., Swarup, S., 2024. Organic matter stability and lability in terrestrial and aquatic ecosystems: A chemical and microbial perspective. Science of The Total Environment, 906: 167757.

Wang, H., Zheng, C., Ning, S., Cao, C., Li, K., Dang, H., Wu, Y., Zhang, J., 2023. Impacts of long-term saline water irrigation on soil properties and crop yields under maize-wheat crop rotation. Agricultural Water Management, 286: 108383.

Yalin, D., Hillary, A. C., Shmuel, A., Evyatar, B.M., Alon Ben-Gal, N., Rabia, M. C., Benny, C., Despo, F., Bernd, M., Gawlik, K. A., Hamilton, L. K., Isaya, K., Iftach, K., Hila, K., Daniel, K., Guy, J. L., Roberta, M., Sixto, M., Célia, M. M., Kyriakos, M., Orah, F. M., Andrew, R., Luigi, R., David, L. S., Maya, S., Eliav, S., Jorge, T., Venus, W., Clinton, W., Jean,M., Eddie, C., 2023. Mitigating risks and maximizing sustainability of treated wastewater reuse for irrigation. Water Research X, 21: 100203.

Zhang, J., Wang, H., Feng, D., Cao, C., Zheng, C., Dang, H., Li, K., Gao, Y., Sun, C., 2024. Evaluating the impacts of long-term saline water irrigation on soil salinity and cotton yield under plastic film mulching: A 15-year field study. Agricultural Water Management, 293: 108703.