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Role of Soil Conditioners in Improving the Soil Physical and Chemical Properties and the Garlic Productivity

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ABSTRACT

Agriculture in Egypt faces increasing challenges related to soil fertility and suitability for crop production, particularly with the growing reliance on marginal lands. Therefore, this study aims to evaluate the impact of certain inorganic soil amendments (bentonite and zeolite), applied alone or in combination with different sources of organic fertilizers (farmyard manure, chicken manure and compost) on improving the physical and chemical properties of a medium-textured soil and their effects on the garlic performance. The results show that applying zeolite, bentonite and organic fertilizers significantly improved the studied soil properties, including enhanced water holding capacity, total porosity, reduced bulk density and improved nutrient retention, as the superior combined treatment was compost+ zeolite. Regarding the plant growth performance (*e.g.,* plant height, leaf area, chlorophyll and NPK) , garlic yield (*e.g.,* bulb diameter and weight, total and marketable yield) and quality (*e.g.,* carbohydrate, vitamin C), the sequence order of inorganic amendments from top effective to less was zeolite followed by bentonite then control, while the sequence order of organic amendments from top effective to less was compost followed by ChM, FYM and control, respectively. Regarding the interaction effect, the superior combined treatment for obtaining the highest values was zeolite x compost. Based on these findings, it is recommended to adopt an integrated soil amendment strategy that combines natural mineral conditioners like zeolite or bentonite with organic matter sources. This approach not only boosts garlic productivity and quality but also contributes to long-term soil fertility and sustainability, especially in the medium-textured soils.

Keywords: Bentonite, Zeolite, FYM, ChM, Compost

INTRODUCTION

Agriculture in Egypt faces increasing challenges related to soil fertility and suitability for crop production, particularly with the growing reliance on marginal lands (El-Ramady *et al.* 2019). Medium-textured soils (with medium sand content) are considered favorable for agriculture due to their balanced properties, moderate water retention, acceptable aeration, and good fertility. However, they are not without challenges. One of the main issues is the gradual loss of water and nutrients, especially under improper irrigation or low organic matter content. While these soils can retain moisture reasonably well, a portion of the water may still percolate down to deeper layers, carrying with it soluble nutrients like nitrates and potassium, leading to leaching losses. Additionally, the moderate porosity does not entirely prevent downward seepage, particularly when the soil surface becomes compacted or develops cracks during dry periods. As a result, inefficient irrigation and fertilization practices can lead to significant wastage of both water and fertilizers, ultimately reducing crop productivity (Selmy *et al.* 2022; Abdullahi *et al.* 2025). Therefore, it is essential to apply materials capable of enhancing their physical and chemical properties to improve their productivity and ensure sustainable agricultural use and enhance its capacity to retain both moisture and nutrients effectively (El-Khalifa *et al.* 2022). Bentonite, a type of clay mineral, is known for its high water-holding capacity and cation exchange properties. Its application can significantly improve the moisture and nutrient retention of the medium-textured soils, reducing losses through leaching (Abdel-Motaleb *et al.* 2025; Weijing *et al.* 2025). Zeolite**,** on the other hand, is a natural crystalline mineral with a porous structure and high cation exchange capacity. It is capable of regulating nutrient release in the soil, thereby enhancing soil fertility and supporting sustainable crop production (Jabbar, 2025; Kukowska & Szewczuk-Karpisz, 2025). Additionally, organic fertilizers, such as farmyard manure, chicken manure and compost, play a crucial role in enriching the soil with organic matter, improving soil structure, and stimulating beneficial microbial activity (Subbaiah, 2019; Singh *et al.* 2020). This leads to a natural and sustainable increase in soil fertility and overall soil health. Therefore, this study aims to evaluate the impact of certain inorganic soil amendments (bentonite and zeolite), applied alone or in combination with different sources of organic fertilizers (farmyard manure, chicken manure and compost), on improving the physical and chemical properties of a medium-textured soil and their effects on the growth, yield and quality of garlic crop.

MATERIALS AND METHODS

A field experiment was implemented under a sandy clay loam soil conditions, characterized by 50% sand, 18% silt and 32% clay, during two successive growing seasons (2023/24 and 2024/25). The experiment was implemented in a private farm located at El-Dakahlia Governorate near Takha City. Soil samples were collected before planting and after harvest for analyses, following the standard procedures

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outlined by Tandon, (2005). The experimental design used in this investigation was a split-plot design with three replicates. The main factor was inorganic amendments [Control (without), bentonite (at rate of ٠.8 tons fed⁻¹) and zeolite (at rate of ٠.8 tons fed⁻¹)], while the sub-plots included four organic fertilizers [Control (without), farmyard manure FYM (applied at 5.0 tons fed⁻¹), chicken manure ChM (applied at 5.0 tons fed⁻¹) and compost (applied at 5 tons fed⁻¹)]. The organic and inorganic amendments were analyzed using the standard methods described by Tandon, (2005), as their characteristics are shown in Table1.

Table 1. Organic and inorganic amendments characteristics

Characteristics	Organic amendments		
	Chicken manure	Compost	Farmyard manure
pH	6.34	6.10	6.30
EC,dSm^{-1}	4.20	3.30	3.95
P , %	0.69	0.88	0.44
K, %	0.88	1.06	0.66
Mn, mg kg^{-1}	23.2	27.6	20.0
Zn , mg kg^{-1}	28.0	30.1	18.7
Total C, %	20.0	19.3	17.22
Total N, %	1.35	1.50	1.25
C:N ratio	14.81	12.87	13.78
OM,%	34.4	33.2	29.62

Inorganic amendments		
Properties	Bentonite	Zeolite
SiO_2	59.2	65.0
Fe_2O_3	3.3	6.0
Al_2O_3	19.3	13.0
CEC, cmol kg^{-1}	79.5	159
EC, dSm^{-1} (1:10)	2.30	2.51

All amendments (organic and inorganic) were incorporated into the soil prior to planting. Garlic cloves (cv. Seds 40) were obtained from Ministry of Agricultural and Soil Reclamation (MASR) in Egypt then were planted on November 1st each season with 15 cm spacing between plants. Fertilization was carried out via fertigation using 120 kg N fed⁻¹ as urea, 60 kg P_2O_5 fed⁻¹ as phosphoric acid and 48 kg K_2O fed⁻¹ as potassium sulphate. Standard agronomic practices were followed throughout the growing season as mentioned by MASR.

At 100 days after planting, vegetative growth parameters [*e.g.,* plant height (cm), No. of leaves plant^{-1}, fresh and dry weights (g plant^{-1}), leaf area (cm^2 plant^{-1})] were measured. Additionally, at the same period, the photosynthetic pigments [chlorophyll a, b and carotene (mg g^{-1})] were determined according to Rai, (1973) using spectrophotometer apparatus as well as leaf chemical constituents (*e.g.,* NPK, %) were estimated as described by Walinga *et al.* (2013), as the sample digestion was done as reported by Peterburgski, (1968).

At harvest (175 days after planting), yield traits [including average bulb weight (g), Bulb diameter (cm), neck diameter (cm), bulbing ratio, No. of cloves bulb^{-1}, total and marketable bulb yield (ton ha^{-1})] were measured. Also, quality traits were determined according to AOAC, (2007) at harvest stage including carbohydrates (%), TSS (%), vitamin C (mg 100g^{-1}), dry matter (%) and pungency (purvate content πmol.ml^{-1}).

Additionally, post-harvest soil analysis was carried out [including bulk density (gcm^3), total porosity (%), cation exchange capacity CEC (cmolkg^{-1}), available NPK (mg kg^{-1}) and water holding capacity WHC (%)] according the standard methods as described by Sparks *et al.,* (2020) and Dane and Topp, (2020) to evaluate soil properties at harvest time. The obtained data of plant performance were subjected to statistical analysis as described by Gomez and Gomez (1984) using analysis of variance (ANOVA).

RESULTS AND DISCUSSION

1.Soil Properties at Harvest

All soil properties at harvest time, including bulk density (gcm^3), total porosity (%), cation exchange capacity CEC (cmolkg^{-1}), available NPK (mg kg^{-1}) and water holding capacity WHC (%) pronouncedly affected due to the studied organic amendments (FYM, ChM AND compost) and inorganic amendments (bentonite and zeolite) during both studied seasons (Table 2), as there were an improvements in these physical and chemical characteristics. Bulk density decreased with all treatments compared to initial soil, as the lowest value was achieved with the combination of compost and zeolite. This reduction is attributed to the incorporation of low-density organic matter, which improves soil structure and reduces compaction.

The high porosity and structural benefits of zeolite and bentonite that promote better soil aggregation. Enhanced microbial activity stimulated by organic inputs, which contributes to the formation of stable soil aggregates with lower density. An increase in total porosity was observed in most treatments, particularly with organic amendments combined with zeolite. This is likely due to improve the soil aggregation and reduced bulk density. Additionally, the organic matter creating micro and macrospores in the soil matrix.

Better aeration and water movement because of a more open soil structure. CEC improved pronouncedly in all treatments, most notably with zeolite application. Zeolite and bentonite had high natural cation exchange capacities, which enhance nutrient retention. The addition of organic materials may have contributed to CEC through humic substances and colloidal particles. Improved soil structure and moisture retention may have increased the contact between exchange sites and soil solution.

All nutrient levels (NPK) increased as a result of the treatments and this trend may be attributed to the nutrient-rich content of organic amendments, especially chicken manure and compost. Additionally the ability of zeolite and bentonite to reduce nutrient leaching by retaining cations and anions may have played an unique role in increasing the values of NPK. Gradual mineralization of organic matter may have caused ensuring a continuous supply of nutrients throughout the season. Moreover, there were an enhanced root access to nutrients due to improved soil porosity and aeration. Also, it can be noticed that the water retention capacity (WHC) improved markedly, particularly with bentonite and zeolite applications, as this may be due to the swelling and water-absorbing capacity of bentonite, which traps moisture within its layered structure as well as zeolite's high internal surface area and porous nature, which increase the soil's ability to retain water. Generally, it can be said that the combined effect of organic matter and minerals improving the overall water-holding characteristics of the soil profile. The obtained results are in harmony with those of Singh *et al.* (2020); Weijing *et al.* (2025); Kukowska & Szewczuk-Karpisz, (2025).

Table 2. Effect of soil amendments on the soil physical and chemical properties (as average) at harvest time during both studied seasons (2023/24 and 2024/25)

Parameters		Bulk density, g cm^3		Total porosity,%		CEC, cmolkg^{-1}		N, mg kg		P, mg kg		K, mg kg		WHC,%	
Initial status (before sowing)		**1.412**		**42.4**		**21.0**		**19.42**		**4.65**		**148.8**		**23.58**	
Treatments		**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Control	Control	1.4	1.41	41.8	42.1	20.7	20.5	20.85	21.73	5.52	5.70	156.02	157.19	23.68	23.83
	FYM	1.35	1.37	44.9	44.6	22.3	22.5	22.11	22.99	5.67	5.85	158.06	159.25	23.74	23.95
	ChM	1.31	1.3	45.9	45.5	23.3	23.1	22.29	23.32	5.78	5.95	159.49	161.02	23.79	23.93
	Compost	1.29	1.28	46.9	46.7	24.4	24.5	22.52	23.47	5.91	6.09	161.58	163.25	23.83	23.97
Bentonite	Control	1.38	1.39	43.9	43.4	24.4	24.1	23.12	24.04	6.10	6.27	167.01	168.41	23.95	24.13
	FYM	1.29	1.29	46.9	47.0	25.9	25.7	23.32	24.23	6.19	6.42	169.05	170.6	24.06	24.2
	ChM	1.27	1.29	47.9	47.5	26.9	27.0	23.47	24.36	6.26	6.48	170.69	172.26	24.16	24.33
	Compost	1.24	1.23	49.0	49.3	28.0	27.8	23.69	24.61	6.34	6.52	172.72	174.19	24.32	24.51
Zeolite	Control	1.36	1.34	44.9	44.5	25.9	25.8	24.14	25.13	6.55	6.73	176.18	177.57	24.50	24.67
	FYM	1.26	1.22	47.9	47.3	29.0	29.0	24.62	25.60	6.73	6.93	178.46	180.39	24.76	25.00
	ChM	1.23	1.22	48.9	48.0	17.5	18.0	25.05	26.08	6.88	7.11	130.34	157.19	24.88	25.18
	Compost	1.20	1.20	49.9	49.3	19.1	19.3	25.44	26.56	7.02	7.26	132.46	159.25	25.23	25.5

2.Growth Criteria, Photosynthetic Pigments and Chemical Constituents at 100 Days from Sowing

All studied treatments (organic and in organic amendments) significantly affected vegetative growth parameters [*e.g.,* plant height (cm), No. of leaves plant^{-1}, fresh and dry weights (g plant^{-1}), leaf area (cm^2 plant^{-1})], photosynthetic pigments [chlorophyll a, b and carotene (mg g^{-1})] and leaf chemical constituents (*e.g.,* NPK, %) at 100 days after planting during both studied seasons. regarding the individual effect of inorganic amendments the highest values of all aforementioned traits were recorded with zeolite followed by bentonite then control (without zeolite or bentonite). Concerning the organic amendments, the superior organic fertilizer for obtaining the maximum values of all aforementioned traits was compost followed by ChM then FYM, while the lowest values were recorded with control treatment (without any organic fertilizers). In terms of interaction effect, the superior combined treatment for obtaining the highest values was zeolite x compost**.** The observed improvements in garlic performance at 100 days from planting can be scientifically attributed to the beneficial effects of soil amendments on soil physical and chemical properties.

Table 3. Effect of the soil amendments on the growth criteria of garlic at 100 days from sowing during season of 2023/24 and 2024/25

Treatments		Plant height, cm		No. of leaves plant^{-1}		Fresh weight, g plant^{-1}		Dry weight, g plant^{-1}		Leaf area, cm^2 plant^{-1}	
		1st season	**2nd Season**	**1st season**	**2nd Season**	**1st season**	**2nd Season**	**1st season**	**2nd Season**	**1st season**	**2nd Season**
Main factor											
Control		70.57c	72.73c	5.00b	6.92c	76.93c	80.20c	16.86c	17.52c	272.08c	276.04c
Bentonite		73.87b	76.23b	7.75a	8.25b	81.10b	84.29b	18.06b	18.83b	309.13b	313.27b
Zeolite		76.21a	78.64a	8.25a	9.25a	83.04a	86.47a	18.61a	19.40a	322.67a	327.27a
F test		**	**	*	*	**	**	**	**	**	**
LSD at 5%		1.32	0.60	0.65	0.79	0.77	1.77	0.05	0.17	5.62	5.13
Sub main factor											
Control		71.90c	73.97c	6.00b	6.89c	78.56b	81.77b	17.39c	18.09c	289.70c	293.46c
FYM		73.47b	75.91b	7.11a	8.11b	80.53a	83.71ab	17.88b	18.58b	299.32b	303.53b
ChM		74.09ab	76.54ab	7.33a	8.56ab	80.83a	84.27a	18.01ab	18.78ab	302.37b	306.78b
Compost		74.74a	77.05a	7.56a	9.00a	81.51a	84.87a	18.10a	18.87a	313.78a	318.34a
F test		**	**	*	**	*	*	**	**	**	**
LSD at 5%		0.90	0.91	0.60	0.66	1.20	2.47	0.21	0.22	3.63	3.40
Interactions											
Control	Control	69.87	72.03	4.00	6.33	76.42	79.62	16.70	17.34	263.47	267.07
	FYM	70.03	72.27	4.33	6.33	76.47	79.46	16.75	17.39	265.57	269.28
	ChM	71.03	73.09	5.67	7.33	76.96	80.60	16.99	17.64	266.03	269.54
	Compost	71.34	73.54	6.00	7.67	77.86	81.13	17.00	17.70	293.23	298.26
Bentonite	Control	72.81	74.74	7.00	7.00	79.28	82.47	17.70	18.43	302.40	306.14
	FYM	73.75	76.52	8.33	8.33	81.34	84.61	18.12	18.83	307.37	311.45
	ChM	74.38	77.08	8.33	8.67	81.51	84.61	18.16	18.98	311.24	316.02
	Compost	74.53	76.58	7.33	9.00	82.29	85.46	18.28	19.06	315.50	319.48
Zeolite	Control	73.02	75.14	7.00	7.33	79.99	83.23	17.76	18.49	303.23	307.17
	FYM	76.63	78.93	8.67	9.67	83.77	87.04	18.76	19.53	325.01	329.87
	ChM	76.85	79.47	8.00	9.67	84.03	87.59	18.88	19.73	329.83	334.79
	Compost	78.34	81.04	9.33	10.33	84.38	88.03	19.02	19.83	332.61	337.27
F test		*	**	*	*	*	*	*	*	**	**
LSD at 5%		1.56	1.56	1.04	1.14	2.08	4.28	0.36	0.39	6.29	5.89

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

Table 4. Effect of the soil amendments on the photosynthetic pigments and chemical constituents in leaves of garlic at 100 days from sowing during season of 2023/24 and 2024/25

Treatments		Chlorophyll a, mg g^{-1}		Chlorophyll b, mg g^{-1}		Carotene, mg g^{-1}		N, %		P, %		K, %	
		1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
Main factor													
Control		0.835c	0.873c	0.609c	0.636c	0.268c	0.281c	2.99c	3.03c	0.299c	0.314c	2.48c	2.51c
Bentonite		0.868b	0.909b	0.653b	0.687b	0.314b	0.330b	3.39b	3.44b	0.326b	0.343b	2.78b	2.82b
Zeolite		0.917a	0.963a	0.680a	0.714a	0.327a	0.344a	3.55a	3.60a	0.339a	0.355a	2.83a	2.88a
F test		**	**	**	**	**	**	**	**	**	**	**	**
LSD at 5%		0.015	0.017	0.013	0.007	0.003	0.005	0.05	0.07	0.005	0.006	0.12	0.03
Sub main factor													
Control		0.846c	0.889c	0.631c	0.659b	0.279d	0.293d	3.13d	3.17b	0.310c	0.326c	2.60c	2.64c
FYM		0.873b	0.917b	0.649b	0.681a	0.306c	0.321c	3.33c	3.37a	0.322b	0.338b	2.69b	2.73b
ChM		0.882ab	0.924ab	0.653ab	0.686a	0.311b	0.327b	3.37b	3.42a	0.324b	0.341ab	2.73ab	2.77a
Compost		0.890a	0.931a	0.657a	0.689a	0.315a	0.332a	3.41a	3.46a	0.329a	0.344a	2.76a	2.81a
F test		**	**	**	*	**	**	**	*	*	**	**	**
LSD at 5%		0.010	0.011	0.005	0.009	0.002	0.004	0.04	0.10	0.004	0.004	0.07	0.03
Interactions													
Control	Control	0.825	0.867	0.602	0.623	0.248	0.260	2.93	2.97	0.293	0.308	2.41	2.44
	FYM	0.834	0.877	0.608	0.634	0.269	0.282	2.97	3.01	0.298	0.313	2.48	2.51
	ChM	0.836	0.875	0.610	0.640	0.275	0.290	3.00	3.04	0.301	0.317	2.50	2.54
	Compost	0.843	0.874	0.616	0.645	0.280	0.294	3.06	3.11	0.305	0.320	2.53	2.57
Bentonite	Control	0.854	0.895	0.642	0.675	0.293	0.307	3.21	3.27	0.316	0.333	2.69	2.73
	FYM	0.864	0.906	0.652	0.686	0.317	0.332	3.42	3.46	0.327	0.344	2.78	2.82
	ChM	0.871	0.912	0.658	0.692	0.322	0.338	3.43	3.48	0.328	0.345	2.81	2.85
	Compost	0.880	0.924	0.661	0.694	0.326	0.343	3.48	3.54	0.333	0.349	2.84	2.89
Zeolite	Control	0.858	0.904	0.648	0.678	0.298	0.312	3.25	3.28	0.322	0.337	2.71	2.76
	FYM	0.922	0.969	0.687	0.723	0.333	0.350	3.59	3.63	0.341	0.358	2.81	2.85
	ChM	0.939	0.984	0.690	0.725	0.336	0.353	3.67	3.73	0.343	0.361	2.89	2.94
	Compost	0.947	0.994	0.695	0.728	0.341	0.360	3.69	3.74	0.348	0.364	2.92	2.96
F test		**	**	**	*	**	*	**	*	*	*	*	*
LSD at 5%		0.019	0.019	0.010	0.017	0.004	0.007	0.07	0.17	0.007	0.007	0.13	0.06

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

Organic amendments like compost, farmyard manure (FYM), and chicken manure (ChM) improved nutrient availability, especially nitrogen, phosphorus, and potassium, through the gradual mineralization of organic matter, thereby enhancing plant growth. Simultaneously, inorganic amendments such as bentonite and zeolite contributed to improved soil structure, moisture retention, and nutrient-holding capacity due to their high cation exchange capacity and porous structure. These physical enhancements created a more favorable rhizosphere environment, leading to better root development and nutrient uptake. Notably, treatments that combined zeolite or bentonite with organic matter showed the greatest growth responses, likely due to synergistic effects that improved both the immediate availability and long-term retention of essential nutrients. The enhancement in photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids) is directly linked to better nitrogen availability, which is crucial for chlorophyll synthesis. The increase in leaf nitrogen content, observed particularly in compost and zeolite treatments, likely contributed to the higher pigment concentrations, thereby improving photosynthetic efficiency and plant vigor. Furthermore, the improved potassium and phosphorus levels in leaves reflect enhanced root activity and nutrient absorption, facilitated by the amendments' effects on soil water-holding capacity and aeration. This, in turn, supports key physiological processes such as ATP synthesis, enzyme activation, and stomatal regulation, which are vital for efficient photosynthesis and biomass accumulation (Subbaiah, 2019; Abdel-Motaleb *et al.* 2025; Kukowska & Szewczuk-Karpisz, 2025).

3.Bulb Yield Traits

Table 5 show the effect of the studied treatments on the yield traits, including average bulb weight (g), bulb diameter (cm), neck diameter (cm), bulbing ratio, No. of cloves $bulb^{-1}$, total and marketable bulb yield (ton ha^{-1}) at harvest stage during both studied seasons. While Table 6 illustrates the effect of the studied treatments on the quality traits at harvest stage including, carbohydrates (%), TSS (%), vitamin C (mg $100g^{-1}$), dry matter (%) and pungency (purvate content $\pi mol.ml^{-1}$) during both studied seasons. The sequence order of inorganic amendments from top effective to less was zeolite followed by bentonite then control, while the sequence order of organic amendments from top effective to less was compost followed by ChM, FYM and control, respectively. In terms of interaction effect, the superior combined treatment for obtaining the highest values was zeolite x compost. The enhancement in garlic bulb yield and quality traits observed across the studied seasons can be scientifically explained by the beneficial impacts of soil amendments on soil fertility, structure, and nutrient availability. Treatments with zeolite and bentonite significantly outperformed the control in bulb weight, diameter, neck thickness, bulbing ratio, and total yield. This is attributed to their high cation exchange capacity and water retention properties, which improve nutrient availability and reduce leaching, particularly of potassium and ammonium ions critical for bulb development. Zeolite, in particular, led to the highest yield values, suggesting its superior capacity to sustain nutrient release throughout the growing season.

Organic amendments also contributed positively to yield traits by gradually mineralizing organic matter, thus enriching the soil with essential macro and micronutrients. This continuous nutrient supply supported vigorous vegetative growth and optimal bulb formation. The interaction between mineral (zeolite or bentonite) and organic amendments resulted in synergistic effects, enhancing both immediate nutrient availability and long-term soil health, leading to increases in bulb size, number of cloves, and marketable yield. Compost, in particular, showed the highest performance among organic treatments due to its balanced nutrient profile and improvement of soil microbial activity.

Table 5. Effect of the soil amendments on the bulb yield traits of garlic at 175 days from sowing (harvest time) during season of 2023/24 and 2024/25

Treatments		Average bulb weight, g		Bulb diameter, cm		Neck diameter, cm		Bulbing ratio		No. of cloves bulb^{-1}		Bulb yield, ton ha^{-1}		Marketable yield, ton ha^{-1}	
		1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season	1st season	2nd Season
Main factor															
Control		39.40c	40.26c	3.30c	3.35c	0.87c	0.89c	0.26b	0.26b	20.92c	25.42b	14.66c	14.88c	13.77c	14.01c
Bentonite		47.00b	48.15b	3.72b	3.79b	1.06b	1.08b	0.29a	0.29a	25.42b	28.00a	16.73b	17.00b	15.50b	15.70b
Zeolite		48.31a	49.45a	3.92a	3.99a	1.16a	1.18a	0.30a	0.30a	27.33a	28.83a	17.48a	17.73a	15.91a	16.13a
F test		**	**	**	**	**	**	*	*	**	*	**	**	**	**
LSD at 5%		0.15	0.77	0.08	0.04	0.07	0.07	0.02	0.02	1.80	1.16	0.05	0.16	0.17	0.13
Sub main factor															
Control		43.57c	44.62c	3.48c	3.55d	0.94b	0.96c	0.27b	0.27b	22.22c	25.89b	15.62c	15.88c	14.59c	14.78c
FYM		44.91b	45.85b	3.62b	3.68c	1.04a	1.06b	0.29ab	0.29a	24.89b	27.78a	16.36b	16.61b	15.08b	15.31b
ChM		45.37ab	46.47a	3.69ab	3.75b	1.05a	1.07ab	0.28ab	0.28a	25.22ab	27.56a	16.50ab	16.71ab	15.22ab	15.46ab
Compost		45.75a	46.87a	3.79a	3.86a	1.08a	1.10a	0.28a	0.28a	25.89a	28.44a	16.68a	16.95a	15.33a	15.56a
F test		**	**	**	**	*	**	*	*	**	*	**	**	**	**
LSD at 5%		0.53	0.51	0.11	0.04	0.04	0.04	0.02	0.01	0.84	1.65	0.19	0.25	0.19	0.23
Interactions															
Control	Control	38.81	39.68	3.20	3.25	0.84	0.85	0.26	0.26	19.33	26.33	14.33	14.56	13.49	13.66
	FYM	39.07	39.87	3.24	3.29	0.86	0.88	0.27	0.27	21.00	23.33	14.61	14.83	13.65	13.89
	ChM	39.75	40.65	3.32	3.38	0.87	0.89	0.26	0.26	21.33	24.33	14.68	14.87	13.90	14.15
	Compost	39.96	40.83	3.43	3.49	0.90	0.92	0.26	0.26	22.00	27.67	15.00	15.27	14.04	14.31
Bentonite	Control	45.85	46.94	3.59	3.66	0.98	1.00	0.27	0.27	23.00	25.33	16.19	16.49	15.01	15.19
	FYM	46.90	47.78	3.69	3.76	1.07	1.09	0.29	0.29	25.67	29.67	16.72	17.04	15.54	15.75
	ChM	47.40	48.80	3.75	3.82	1.08	1.10	0.29	0.29	26.00	29.00	16.97	17.18	15.64	15.87
	Compost	47.84	49.08	3.85	3.92	1.11	1.14	0.29	0.29	27.00	28.00	17.05	17.30	15.80	16.00
Zeolite	Control	46.05	47.24	3.66	3.73	1.01	1.03	0.28	0.28	24.33	26.00	16.35	16.59	15.27	15.47
	FYM	48.75	49.91	3.92	4.00	1.19	1.21	0.30	0.30	28.00	30.33	17.74	17.97	16.05	16.30
	ChM	48.97	49.96	4.00	4.07	1.21	1.23	0.30	0.30	28.33	29.33	17.84	18.07	16.14	16.37
	Compost	49.45	50.70	4.09	4.17	1.22	1.24	0.30	0.30	28.67	29.67	17.98	18.28	16.16	16.37
F test		*	*	*	**	*	*	*	*	*	*	**	*	*	*
LSD at 5%		0.91	0.88	0.18	0.08	0.07	0.07	0.03	0.01	1.45	2.84	0.33	0.43	0.33	0.40

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

Table 6. Effect of the soil amendments on the bulb quality traits of garlic at 175 days from sowing (harvest time) during season of 2023/24 and 2024/25

Treatments		Carbohydrates, %		TSS, %		Vitamin C, mg 100g^{-1}		Dry matter, %		Pungency, purvate content πmol.ml^{-1}	
		1st season	2ndSeason	1stseason	2ndSeason	1st season	2ndseason	1stseason	2ndseason	1st season	2ndseason
Main factor											
Control		24.80c	25.15b	25.47c	25.82c	15.00c	15.25c	21.92b	22.40c	11.41c	11.62c
Bentonite		26.49b	26.86a	26.98b	27.37b	15.82b	16.11b	24.12a	24.71b	12.41b	12.63b
Zeolite		27.08a	27.47a	27.62a	28.04a	16.15a	16.44a	24.71a	25.30a	12.91a	13.11a
F test		**	*	**	**	**	**	*	**	**	**
LSD at 5%		0.53	0.88	0.25	0.45	0.25	0.13	0.79	0.49	0.12	0.13
Sub main factor											
Control		25.44c	25.82b	26.09c	26.47b	15.23b	15.48c	22.40b	22.93c	11.82c	12.03c
FYM		26.10b	26.43a	26.62b	27.01ab	15.66a	15.94b	23.71a	24.22b	12.25b	12.48b
ChM		26.44a	26.84a	26.91ab	27.30a	15.80a	16.09ab	24.03a	24.61a	12.34b	12.55b
Compost		26.51a	26.88a	27.13a	27.54a	15.93a	16.22a	24.19a	24.79a	12.56a	12.75a
F test		**	*	**	*	*	**	*	**	**	**
LSD at 5%		0.23	0.60	040	0.73	0.40	0.24	0.53	0.21	018	0.10
Interactions											
Control	Control	24.48	24.89	25.16	25.53	14.61	14.83	21.36	21.81	11.15	11.33
	FYM	24.62	24.90	25.29	25.66	14.98	15.24	21.80	22.28	11.32	11.53
	ChM	25.00	25.36	25.67	25.99	15.14	15.38	22.22	22.74	11.47	11.69
	Compost	25.09	25.45	25.75	26.10	15.27	15.56	22.29	22.78	11.71	11.93
Bentonite	Control	25.76	26.16	26.47	26.82	15.48	15.76	22.84	23.35	12.07	12.29
	FYM	26.44	26.77	26.83	27.22	15.80	16.12	24.36	24.86	12.41	12.64
	ChM	26.85	27.25	27.04	27.45	15.90	16.19	24.45	25.13	12.49	12.71
	Compost	26.90	27.26	27.57	28.01	16.08	16.36	24.85	25.51	12.68	12.89
Zeolite	Control	26.08	26.42	26.65	27.04	15.60	15.84	23.01	23.63	12.25	12.48
	FYM	27.23	27.62	27.73	28.15	16.20	16.46	24.97	25.53	13.03	13.27
	ChM	27.48	27.90	28.03	28.46	16.37	16.70	25.41	25.96	13.05	13.26
	Compost	27.55	27.94	28.08	28.50	16.44	16.75	25.45	26.09	13.30	13.44
F test		*	*	*	*	*	*	*	**	*	**
LSD at 5%		0.40	1.03	0.69	1.26	0.69	0.41	0.92	0.36	0.32	0.17

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

Regarding quality parameters, soil amendments significantly improved carbohydrate content, total soluble solids (TSS), vitamin C, dry matter, and pungency (pyruvate content). These improvements are closely linked to better nutrient uptake, especially nitrogen, potassium, and sulfur, which play essential roles in carbohydrate metabolism, ascorbic acid synthesis, and sulfur-containing compound formation, respectively. Zeolite-amended soils produced garlic with the highest quality attributes, likely due to enhanced nutrient efficiency and reduced nutrient losses. Compost again showed superior performance among organic sources, improving dry matter and bioactive compounds, which are key quality indicators for garlic flavor, storage, and nutritional value. The obtained results are in agreement with those of Subbaiah, (2019); Singh *et al.* (2020); Abdel-Motaleb *et al.* (2025); Kukowska & Szewczuk-Karpisz, (2025); Weijing *et al.* (2025).

CONCLUSION

The present study clearly demonstrates that the application of soil amendments such as zeolite, bentonite, and organic fertilizers significantly improved the physicochemical properties of the medium-textured soils, including enhanced water holding capacity, total porosity, reduced bulk density, and improved nutrient retention. These improvements had a direct positive impact on garlic plant growth, bulb development, and quality traits during both growing seasons. Among all treatments, zeolite combined with compost was the most effective, resulting in the highest yield and quality parameters. This indicates the strong synergistic effect between mineral and organic amendments, which enhanced nutrient availability, reduced nutrient losses through leaching or volatilization, and improved soil moisture conservation.

Based on these findings, it is recommended to adopt an integrated soil amendment strategy that combines natural mineral conditioners like zeolite or bentonite with organic matter sources. This approach not only boosts garlic productivity and quality but also contributes to long-term soil fertility and sustainability, especially in medium-textured soils.

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دور محسنات التربة علي تحسين خواص الأرض الطبيعيه والكميائيه وانتاجيه محصول الثوم

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الملخص

تواجه الزراعة في مصر تحديات متزايدة تتعلق بخصوبة التربة وملاءمتها للإنتاج الزراعي، لا سيما مع الاعتماد المتزايد على الأراضي الهامشية. لذلك، تهدف هذه الدراسة إلى تقييم تأثير بعض المحسنات غير العضوية للتربة (البنتونيت والزيوليت)، سواء عند استخدامها بمفردها أو بالتكامل مع مصادر مختلفة من الأسمدة العضوية (السماد البلدي، سماد الدواجن، والكمبوست)، على تحسين الخصائص الفيزيائية والكيميائية لتربة متوسطة القوام، وانعكاسات ذلك على أداء محصول الثوم. أظهرت النتائج أن إضافة الزيوليت والبنتونيت والأسمدة العضوية قد حسّنت بشكل ملحوظ من خصائص التربة المدروسة، بما في ذلك زيادة السعة الحقلية للماء، وارتفاع المسامية الكلية، وانخفاض الكثافة الظاهرية، وتحسين الاحتفاظ بالعناصر الغذائية. وقد كان أفضل المعاملات المشتركة هو اضافة الكمبوست مع الزيوليت كمعاملة مشتركة .أما فيما يتعلق بأداء نمو النبات (مثل طول النبات، مساحة الأوراق، محتوى الكلوروفيل ومحتوي النيتروجين والفسفور والبوتاسيوم) ، وإنتاجية الثوم (مثل قطر ووزن الرأس، والإنتاج الكلي والتسويقي)، وكذلك جودة المحصول (مثل محتوى الكربوهيدرات وفيتامين C) ، فقد كان ترتيب كفاءة المحسنات غير العضوية من الأعلى إلى الأقل كالتالي: الزيوليت، يليه البنتونيت، ثم المعاملة الكنترول . أما المحسنات العضوية، فجاء الكمبوست في المقدمة، يليه سماد الدواجن، ثم السماد البلدي، وأخيرًا الكنترول.وفيما يتعلق بالتأثير المتداخل بين العوامل، فقد كانت المعاملة المشتركة (زيوليت × كمبوست) هي الأفضل في تحقيق أعلى القيم. وبناءً على هذه النتائج، يُوصى باعتماد استراتيجية متكاملة لتحسين التربة، تجمع بين المحسنات المعدنية الطبيعية مثل الزيوليت أو البنتونيت ومصادر المادة العضوية. إذ يسهم هذا النهج في تعزيز إنتاجية وجودة محصول الثوم، بالإضافة إلى تحسين خصوبة التربة واستدامتها على المدى الطويل، لا سيما في الأراضي المتوسطه القوام.