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Biochar and Gypsum Synergy for Restoring Degraded Desert Soils and Enhancing Lettuce Productivity in Western Iraq

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ABSTRACT: In a field study carried out on desert soil in the Tash area of Anbar Governorate during the cultivation of the lettuce crop in the autumn season of 2025, the effect of adding different levels of biochar (0, 5, 10 tons/hectare) and agricultural gypsum (0, 2, 4 tons/hectare) was tested according to the design of the complete random sectors with three repeaters, to enhance soil properties The results showed moral differences between the parameters at the level of 0.05, as the additions led to a decrease in the apparent density, salinity and the ratio of mutual sodium, and a high porosity, cohesion, organic matter, cation exchange capacity and concentration of nutrients (nitrogen, phosphorus and potassium), due to the carbon-rich porous structure in biochar and its role in nutrient reservation and preventing them, in addition to the role of calcium in agricultural plaster in the cohesion of molecules, reducing their separation and improving ionic balance. The combined treatment (10 tons of bio-coal + 4 tons of gypsum) recorded the best values in most qualities and the highest productivity of lettuce, confirming that the integrated use of these improvers is an effective means of reclaiming dry and semi-arid desert lands and achieving agricultural sustainability.

INTRODUCTION

Lands in the dry and semi-arid ranges face multiple obstacles that limit their production capacity, most notably high salinity, increased sodium, poor structural structure and lack of fertility. These constraints, in turn, negatively affect the survival and continuity of agricultural systems, and threaten food security by weakening the natural and chemical properties of the soil (Lal, 2009; Hillel, 2004; Krishna et al., 2026). Desert lands in western Iraq are a living example of these problems, as they are unable to achieve the appropriate water and nutritional balance of plants, which elements like potassium, phosphorus, and nitrogen that are absorbed (Page et al., 1982; Bremner & Mulvaney, 2025; Zhu et al., 2024). Among the solutions used to address these problems, agricultural gypsum ($CaSO4·2H2O$) comes as an effective chemical improver in sodic land, where calcium ions in it replace the sodium ions on the surfaces of ion exchange, thus reducing the level of mutual sodium, improving the structural qualities of the soil and increasing its ability to pass water and expel excess salts from the root area (Al-Taha, 2025; Wessam et al., 2025; Zhu et al., 2024). Many experiments have confirmed that the addition of gypsum contributes to the sustainability of soil pools and raising their water and nutrients retention efficiency, especially in soft and salty environments (Xu et al., 2023; Alhaj Hamoud et al., 2024).

On the other hand, in the last two decades, Biochar has gained popularity as an organic soil improver., created by the thermal carbonization of organic residues in the absence of oxygen, and is characterized by high porosity, big surface area and exceptional the power to bind and reserve nutrients and water (Lehmann & Joseph, 2015; El-Naggar et al., 2019). The scientific literature indicates that the addition of this coal to the soil brings about improvements in several properties; it increases the cationic It raises the amount of biological matter and exchange ability gains soil pools greater stability, reduces the apparent density and increases the percentage of pores (Glaser et al., 2002; Yulnafatmawita et al., 2023; de Araújo et al., 2024). In addition, biochar leads to an excessive levels of prepared nutrients, including nitrogen, phosphorus and potassium increases the efficiency of utilization of added fertilizers, and then growth improves and yields increase, especially in degraded lands (Umair et al., 2023; Bekele, 2025).

When combining biochar and agricultural gypsum, recent research has proven tangible synergistic effects that are reflected on the ion balance, salt soil rehabilitation, increasing the cohesion of its concentrations and raising its fertility (Xu et al., 2023; SaTian et al., 2024; Alhaj Hamoud et al., 2024). The overlap between organic matter (represented by biochar) and gypsum improves the functioning and recovery of plants under salt stress conditions, as the combination of them gives better results than using each of them alone (Abdelrady et al., 2025; Lan et al., 2026).The purpose of this study is to assess the effects of varying the amounts of agricultural gypsum and biochar.(individual and combined) in improving the properties of degraded desert soil in western Iraq. The tested properties include electrical conductivity, bulk density, porosity, stability of soil pools, organic matter, Exchangeable Sodium Ratio (ESR) , and nutrients (N, P, K), in addition to estimating the reflection of this on the crop of lettuce .

MATERIALS AND METHODS

A field research was carried out to investigate the impact of the interaction between levels of biochar produced from burning palm waste and agricultural gypsum on some Physical and chemical characteristics and soil fertility the Al-Tash region of the Anbar Desert .Table (1) shows some properties of the soil amendments used in the study.

This area is characterized by degraded desert soil suffering from high salinity and sodium levels and low organic matter content. This experiment was performed during the autumn of 2025. The soil was plowed down to a of (25-30 cm) using a moldboard plow and then left for a suitable period of aeration .The surface was leveled using a leveling device, and the area was also divided into equal-sized experimental plots to facilitate planting and irrigation. Furrows 70-80 cm wide were also dug. The experiment was designed using a completely randomized block design, as this design was suitable for the field conditions. The area was divided into several homogeneous units and the processors were randomly distributed within each unit. The experiment was replicated three times. A randomized complete block design (RCBD) with two components and three replicates was used for the experiment.

Factor 1: Biochar

B0 = 0 tons ha^{-1}

B1 = 5 tons ha^{-1}

B2 = 10 tons ha^{-1}

Factor 2: Agricultural Gypsum

G0 = 0 tons ha^{-1}

G1 = 2 tons ha^{-1}

G2 = 4 tons ha^{-1}

Lettuce seeds were sown in plastic containers in a special nursery filled with a suitable soil mix (peat and perlite).

Table (1) These tables characterize the amendment materials used in the study.

materials	**(pH)**	**(EC) ds/m-1**	**Sodium Content %**	**Bulk Density Mg. m^{-3}**	**Available Nitrogen mg. kg^{-1}**	**Available Phosphorus mg. kg^{-1}**	**Available Potassium mg. kg^{-1}**	**(CEC) Cmol.kg-1**
Biochar	8.1	2.14	0.11	0.29	4.22	1.01	6.02	51.1
Agricultural Gypsum	7.3	2.19	0.14	1.13	1.03	0.05	2.40	5.08

The seedlings were kept until they were 3-4 weeks old and had developed 3-4 true leaves, then transplanted to the permanent field on September 20, 2025. They were then planted in rows with 25-30 cm between plants and irrigated with direct drip irrigation after planting to promote root growth.

Properties Studied and Methods of Analysis

1. Electrical Conductivity (EC): The saturated paste extraction was assayed using an electrical conductivity meter designed following Richards, 1954 methods.
2. The Exchangeable Sodium Ratio (ESR) of the study area determined through ammonium acetate method following Richards, 1954 methods.
3. .Soil Organic Carbon: organic matter in the soil was assessed according to the procedures of Walkey and Black (1934),
4. .Bulk Density: was measured using the metal cylinder method according to Blake & Hartge (1986).
5. Total Porosity: It is calculat based on the bulk and true density of the soil according to the standard equation in Hillel (2004).
6. Soil Aggregation Stability: was used to test the stability of the soil aggregate the wet sieving method according to Kemper & Rosenau's (1986) method.
7. Available Nitrogen: was estimated using the modified Kjeldale method Available nitrogen in the soil method according to Mulveney & Bremner. (1982)
8. Available Phosphorus: using Olsen's method available phosphorus in alkaline soils was estimated according to Olsen et al. (1954).
9. Available Potassium: Using a flame photometry device after extraction with ammonium acetate, available potassium was estimated according to Page et al. (1982).
10. Crop Yield: Crop yield was measured at final harvest in tons ha^{-1} using a large balance.

Statistical Analysis:

analyzed data were using analysis of variance (ANOVA) according to the RCBD design and means were compared using the least difference (LSD) test at a probability level of 0.05.

RESULTS AND DISCUSSION

Table (2) the biochar effect agricultural gypsum and their interaction on soil electrical conductivity(ds/m-1)

Biochar	Agricultural gypsum			Average
	G0 (0tan/H)	G1(2 tan/H)	G2(4 tan/H)	
B0(0tan/H)	7.85a	6.40b	5.20c	6.48
B1(5tan/H)	6.70b	5.10c	4.10d	5.3
B2(10tan/H)	5.90c	4.30d	3.20e	4.47
Average	6.82	5.27	4.17	_
LSDB=0.24 LSDG=0.38 LSDB*G=0.65				

The different letters on LSD indicate represent differences at the 0.05 level.

1-Soil Electrical Conductivity:

Table (2) show a important drop in soil electrical conductivity with increasing levels of both biochar and agricultural gypsum. The highest value (7.85 dS/m) was reported in the treatment B0G0, the less value (3.20 dS/m) reported in the therapy B2G2. Different letters indicate statistically significant differences in the table between treatments at a probability level of 0.05. Further , the mean values of the factors show that increasing the biochar level from 0 to 10 tons/hectare reduced the average electrical conductivity from 6.48 to 4.47 dS/m, while increasing the agricultural gypsum level from 0 to 4 tons/hectare decreased it from 6.82 to 4.17 dS/m. It turns out that each factor has a clear and important effect, as demonstrated by the LSD values for both biochar and gypsum, as well as the interaction between them. each of this is requtied to the function of decreased agricultural gypsum in change exchangeable sodium ions with calcium ions in the action exchange complex, which reduces sodium accreltion and improves salt filter from the root zone. Biochar also contributes to improving soil structure and increasing its porosity, which enhances salt filterand reduces salt collection in the soil. Biochar enhance soil structure and porosity, promotes salt drainage and lowers salt growing the soil. Olsen et al. (1954); Bekele (2025).

Table (3) agricultural gypsum and effect of biochar and their interaction on the exchangeable sodium ratio in the soil (%)(ESP) was reported in the control treatment B0G0.

Biochar	Agricultural gypsum			Average
	G0 (0tan/H)	G1(2 tan/H)	G2(4 tan/H)	
B0(0tan/H)	18.6 a	15.2 b	12.8 c	15.5
B1(5tan/H)	16.4b	13.1 c	10.7 d	13.4
B2(10tan/H)	14.2 c	11.3 d	8.9 e	11.5
Average	16.4	13.2	10.8	—
LSDB= 1.24 LSDG= 1.37 LSDB*G=1.92				

The different letters represent differences at the 0.05 level.

2. Sodium Exchangeable (ESP) :

Table(3) findings demonstrate a notable drop in exchangeable sodium when charcoal and agricultural gypsum levels rise. The therapy B2G2 had the lowest value at 8.9%, whereas the control treatment B0G0 had the highest value at 18.6%. The averages of the factors also show that the average ESP decreased from 15.5% to 11.5% when the amount of biochar was increased from 0 to 10 tons ha^{-1}, and from 16.4% to 10.8% when the amount of agricultural gypsum was increased from 0 to 4 tons ha^{-1}.This decline is mostly explained by agricultural gypsum's function in substituting calcium ions for sodium on the cation exchange complex, which lowers exchangeable sodium and increases its leaching from the root zone. Additionally, biochar helps to improve soil structure and permeability, which improves sodium leaching and lessens the sodic impact in the soil. (Krishna et al., 2026).

Table (4) Effect of agricultural gypsum and biochar and their interaction on organic matter in the soil (%)

Biochar	Agricultural gypsum			Average
	G0 (0tan/H)	G1(2 tan/H)	G2(4 tan/H)	
B0(0tan/H)	0.42 e	0.48 d	0.53 c	0.48
B1(5tan/H)	0.58 d	0.64 c	0.71 b	0.64
B2(10tan/H)	0.75 c	0.83 b	0.92 a	0.83

Average	0.58	0.65	0.72	—
LSDB=2.13		LSDG=2.01	LSDB*G=2.84	

The different letters on LSD indicate significant differences at the 0.05 level.

3- Soil Organic Matter:

The results in Table (4) show a clear increase in soil organic matter and its content. Increasing the levels of biochar and agricultural gypsum also led to an increase in organic matter values from 0.42% in the control treatment to 0.92% in the B2G2 treatment. The averages showed that increasing the level of biochar led to an increase in organic matter from 0.48% to 0.83%, while increasing the level of agricultural gypsum led to an average increase from 0.58% to 0.72%. This can be mainly explained by the high content of stabilized organic carbon in biochar, which contributes to increasing the soil's organic matter stock and improving its fertility. Furthermore, improving soil structure using agricultural gypsum helps reduce organic matter decomposition and loss (Zhu et al., 2024).

Table (5): Biochar and agricultural gypsum: their effect and interaction on soil bulk density (Mg. m^{-3})

Biochar	Agricultural gypsum			Average
	G0 (0tan/H)	G1(2 tan/H)	G2(4 tan/H)	
B0(0tan/H)	1.62 a	1.55 b	1.48 c	1.55
B1(5tan/H)	1.54 b	1.46 c	1.38 d	1.46
B2(10tan/H)	1.45 c	1.36 d	1.28 e	1.36
Average	1.54	1.46	1.38	—
LSDB=0.04		LSDG=0.08	LSDB*G=0.06	

Different letters on the LSD scale indicate significant differences at the 0.05 level.

4- Soil Bulk Density:

Table (5) findings demonstrated a significant drop in soil bulk density as charcoal and agricultural gypsum levels increased. The control treatment B0G0 the highest bulk density (1.62 MG/m^3), whereas the treatment B2G2 the lowest bulk density (1.28 MG/m^3). The bulk density dropped from 1.55 to 1.36 MG/m^3 when the biochar level was increased from 0 to 10 tons/hectare, and from 1.54 to 1.38 MG/m^3 when the agricultural gypsum level was increased from 0 to 4 tons/hectare, according to the averages. Because of its high porosity and low density biochar is said to be able to improve soil structure and increase pore volume. As a result, the bulk density decreases and the cohesiveness of the soil particles is diminished. By encouraging soil particle aggregation, which increases pore areas and lowers bulk density, agricultural gypsum also helps to improve soil structure, (Lehmann & Joseph, 2015).

Table (6) Biochar and Agricultural Gypsum Effect and interaction between them in the stability of soil aggregates (%)

Biochar	Agricultural gypsum			Average
	G0 (0tan/H)	G1(2 tan/H)	G2(4 tan/H)	
B0(0tan/H)	e32.4	36.8 d	40.5 c	36.6
B1(5tan/H)	38.7d	43.6 c	48.2 b	43.5

B2(10tan/H)	44.3 c	50.8 b	56.7 a	50.6
Average	38.5	43.7	48.5	—
LSDB= 2.15 LSDG=2.34 LSDB*G= 3.28				

The different letters indicate significant differences at the 0.05 level.

5-Soil Column Stability:

Table (6) shows a significant increase in soil stability with increasing amounts of agricultural gypsum and biochar, both in terms of soil column stability and their interaction. Treatment B2G2 recorded the highest value at 56.7%, while the control treatment B0G0 recorded the lowest value at 32.4%. The different letters in the table represent substantial changes between treatments at a probability level of 0.05. The average soil stability increased from 36.6% to 50.6% when the biochar level increased from 0 to 10 tons/hectare, and from 38.5% to 48.5% when the agricultural gypsum level increased from 0 to 4 tons/hectare. This demonstrates a significant effect of each factor, as biochar increases The soil's organic matter content and improves its structure thus improving soil aggregate stability. Organic matter also helps Acting as a binding agent between soil particles helps to build more stable aggregates. In addition, the highly porous nature of biochar enhanced soil aeration and water distribution, promoting the formation of stable aggregates.

Agricultural gypsum contributes to improving soil stability by increasing the concentration of calcium ions, which reduces the dispersion of clay particles and promotes aggregation, especially in sodic soils. The interaction between biochar and agricultural gypsum has resulted in a clear synergistic effect, as both work together to enhance structure soil and increased aggregate stability.

Improved soil stability is a crucial factor in enhancing physical properties soil such as increased porosity, improved water permeability, and reduced erosion, which positively impacts plant growth and increases nutrient uptake efficiency. (SaTian et al., 2024).

Table (7) (%) Agricultural Gypsum Effect and Biochar their Interaction on Total Soil Porosity

Biochar	Agricultural gypsum			Average
	G0 (0tan/H)	G1(2 tan/H)	G2(4 tan/H)	
B0(0tan/H)	38.2 e	41.5 d	44.3 c	41.3
B1(5tan/H)	42.6 d	46.8 c	49.5 b	46.3
B2(10tan/H)	47.4 c	51.6 b	55.2 a	51.4
Average	42.7	46.6	49.7	—
LSDB=2.13 LSDG=2.01 LSDB*G=2.84				

The different letters on LSD indicate significant differences at the 0.05 level.

6-Total Soil Porosity

The results in Table (7) show a significant increase in total soil porosity and an increase in the levels of biochar and agricultural gypsum. The lowest porosity value (38.2%) was recorded in the control treatment B0G0, while the highest value (55.2%) was recorded in the treatment B2G2. The average porosity increased with increasing levels of agricultural gypsum from 42.7% to 49.7%. The average porosity increased from 41.3% at a zero level of biochar to 51.4% at a level of 10 tons/hectare. The addition of biochar contributed to an increase in soil porosity, while agricultural gypsum contributed to improving soil structure, increasing the cohesion of its particles, and forming stable aggregates, which in turn increased the total volume of soil pores (De Araujo et al., 2024).

Table (8) shows the effect of biochar and agricultural gypsum and their interaction on soil available nitrogen (mg.kg^{-1}).

Biochar	Agricultural gypsum			Average
	G0 (0tan/H)	G1(2 tan/H)	G2(4 tan/H)	
B0(0tan/H)	28.4 e	31.6 d	34.2 c	31.4
B1(5tan/H)	35.8 d	39.5 c	42.7 b	39.3
B2(10tan/H)	44.6 c	48.9 b	53.4 a	49
Average	36.3	40	43.4	—
LSDB=2.13		LSDG=2.01		
LSDB*G=2.84				

The different letters LSD indicate significant differences at the 0.05 level.

7- Available Soil Nitrogen:

Table (8) shows a significant increase in soil nitrogen concentration. Biochar and agricultural gypsum levels also increased, from 28.4 mg. kg^{-1} in the control treatment to 53.4 mg/kg in the B2G2 treatment. The table shows the average increase in available nitrogen from biochar, from 31.4 to 49.0 mg.kg^{-1}, and from agricultural gypsum, from 36.3 to 43.4 mg.kg^{-1}. This is attributed to biochar's ability to increase soil nutrient retention, reduce leaching losses, and enhance biological activity. Furthermore, the application of agricultural gypsum improves soil physical properties and nutrient availability for plants, (Yulnafatmawita et al., 2023).

Table (9) Effect of Biochar and Agricultural Gypsum and Their Interaction on Soil Available Phosphorus (mg. kg^{-1})

Biochar	Agricultural gypsum			Average
	G0 (0tan/H)	G1(2 tan/H)	G2(4 tan/H)	
B0(0tan/H)	8.6 e	9.8 d	11.2 c	9.9
B1(5tan/H)	11.5 d	13.4 c	15.6 b	13.5
B2(10tan/H)	14.2 c	16.8 b	19.5 a	16.8
Average	11.4	13.3	15.4	—
LSDB= 1.12			LSDG=1.34	
LSDB*G= 1.86				

The different letters in the table indicate significant differences at the 0.05 level.

8- Soil-available phosphorus (P):

Table (9) concerning soil phosphorus availability shows a significant increase in phosphorus concentration and an increase in the levels of both biochar and agricultural gypsum, along with an interaction between them. The control treatment (B0G0) recorded the lowest value at 8.6 mg kg^{-1}, while the treatment (B2G2) recorded the highest value at 19.5 mg. kg^{-1}. The different letters in the table indicate statistically significant differences between the treatments at a probability level of 0.05.

Increasing the biochar level from 0 to 10 tons/hectare led to an increase in the average available phosphorus from 9.9 to 16.8 mg. kg^{-1}, as evidenced by the averages of the factors. Likewise, increasing the agricultural gypsum level from 0 to 4 tons/hectare led to an increase in the average available phosphorus from 11.4 to 15.4 mg. kg^{-1}, indicating a significant effect for each factor.

This increase in available phosphorus concentration is due to biochar's ability to boost cation exchange capacity while also enhancing soil physical and chemical properties. This reduces phosphorus fixation while increasing its availability to plants. Also, the

In soil structure resulting from agricultural gypsum contributes to reducing the effects of salinity and sodium, which increases the efficiency of nutrient absorption, including phosphorus. The interaction between biochar and agricultural gypsum has led to a synergistic effect and is reflected in a significant increase in phosphorus availability in the soil, (Umair et al., 2023).

Table (10) Effect of biochar, agricultural gypsum and their interaction on available potassium in the soil (mg kg^{-1})

Biochar	Agricultural gypsum			Average
	G0 (0tan/H)	G1(2 tan/H)	G2(4 tan/H)	
B0(0tan/H)	142 e	155 d	168 c	155
B1(5tan/H)	165d	182 c	205 b	184
B2(10tan/H)	190 c	215 b	238 a	214
Average	166	184	204	—
LSDB= 8.45 LSDG= 10.12 LSDB*G= 14.30				

The different letters LSD indicate significant differences at the 0.05 level.

9- Soil Potassium (K):

The results in Table (10) regarding potassium availability in the soil indicate a significant increase in potassium concentration and increased levels of biochar and agricultural gypsum. The control treatment (B0G0) recorded the lowest value at 142 mg/kg, while the treatment (B2G2) recorded the highest value at 238 mg .kg^{-1}, demonstrating the positive effect of using the soil improvers in increasing potassium availability.

Furthermore, the averages showed that increasing the biochar level from 0 to 10 tons/hectare led to an increase in average available potassium from 155 to 214 mg/kg, while increasing the agricultural gypsum level from 0 to 4 tons/hectare led to an increase in average potassium from 166 to 204 mg kg^{-1}. This indicates a clear and significant effect for each factor individually, as well as for the interaction between them.

The increase in the concentration of available potassium is due to the biochar containing minerals in large quantities, including potassium, in addition to its role in improving the soil's ability to exchange cations and increasing its ability to retain nutrients. Agricultural gypsum contributes to improving soil structure and increasing its permeability and improves plant absorption of nutrients. The interaction between these two factors to a significant improvement soil fertility and an increases in potassium availability ,(Glaser et al., 2002).

Table (11) Effect of biochar, agricultural gypsum, and their interaction on crop yield $(tons/ha)^{-1}$

Biochar	Agricultural gypsum			Average
	G0 (0tan/H)	G1(2 tan/H)	G2(4 tan/H)	
B0(0tan/H)	2.10 e	2.45 d	2.80 c	2.45
B1(5tan/H)	2.75 d	3.20 c	3.65 b	3.2
B2(10tan/H)	3.50 c	4.05 b	4.60 a	4.05
Average	2.78	3.23	3.68	—
LSDB=2.13	LSDB*G=2.84		LSDG=2.01	

The different letters LSD indicate significant differences at the 0.05 level.

10- Crop Yield:

shown in Table (11) demonstrate a important increase in yields crop resulting from the use of biochar and agricultural gypsum. The treatment recorded the yield lowest at 2.10 t/ha treatment B2G2 achieved the yield highest at 4.60 t/ha. increased t he yield average from 2.45 t/ha with zero biochar application to 4.05 t/ha with 10 t/ha. The average yield and application of agricultural gypsum also increased from 2.78 to 3.68 t/ha. This enhancment in productivity is to the merg positive effects of biochar and agricultural gypsum in enhancing the soil's physical and chemical properties fertility promoting plant growth, and increasing nutrient uptake efficiency, (Lan et al., 2026).

The addition of agricultural gypsum and biochar a important impact on improving the physical and chemical properties soil and fertility of degraded desert, as the results showed. the levels of biochar increased and agricultural gypsum led to decrease in electrical conductivity and the exchangeable sodium ratio, indicating an enhance in soil salinity and sodium content. This is mainly to the role of agricultural gypsum in replacing calcium ions with sodium ions in the cation exchange complex, thus facilitating sodium leaching from the root zone. also , biochar improved soil structure and increased its fertility. water permeability, which further enhanced leaching and reduced salt accumulation.

The results showed a marked improvement in the physical properties of the soil with the increase in the proportion of both peat and agricultural gypsum, as the bulk density decreased while both the overall size of the voids and the cohesion increased. This is peat to the containing a high percentage of organic matter and its porous composition, which enhance the texture of the soil increases its ability to retain organic matter and structure. In sodium-rich soils, calcium in agricultural gypsum contributes to the bonding of soil molecules and reducing their separation. With regard to the chemical and fertility properties of the soil, the results showed a marked increase in the content of organic matter and cation exchange capacity, along with an increase in the concentration of plant-made nutrients such as nitrogen, phosphorus and potassium. This is due to the ability of biochar to raise the efficiency of cationic exchange of soil, improve its nutrient retention and reduce its loss by washing, in addition to the nutrients provided by biochar itself. Agricultural gypsum also contributes to achieving better ion balance within the soil and raising the efficiency of plants in absorbing nutrients.

This synergistic effect between the two improved substances is shown in creating the soil environment and he efficiency improving t of the plant's use of nutrients and water . In general, finding of this this study emphasize the importance of integrating the use of biochar and agricultural gypsum as an effective means of improving and reclaiming degraded desert lands, which contributes to increasing crop productivity and sustaining production agricultural in arid and semi-arid areas, (Umair et al., 2023; Bekele, 2025).

CONCLUSIONS

The use of biochar and agricultural gypsum has led to a clear enhancement in the soil natural and chemical properties . The transactions contributed to reducing both salinity and alkalinity (sodium) and raising soil fertility. The composite treatment (10 tons of biocoal + 4 tons of gypsum) has achieved the best results, so it can be adopted in desert soil reclamation programs.

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