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The combined use of biochar and silica nanoparticles contributes to improved wheat (*Triticum aestivum L.*) yield in saline-affected soils.

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Abstract

This field research was conducted during the 2024-2025 growing season at the research station of the College of Agriculture, University of Basrah. The experiment included 12 treatments resulting from the interaction of four levels of silica nanoparticles (0, 200, 300, and 400 kg/ha, respectively) with three levels of locally produced biochar made from wheat straw residue (0, 20, and 30 t/ha, respectively). The wheat variety Research 22" was used in this experiment. The results showed a positive effect of the interaction between" biochar and nano-silica on wheat growth indicators. The treatment (30 t ha^{-1} of biochar + 400 kg ha^{-1} of nano-silica) achieved the highest values for dry straw weight (21.26 t ha^{-1}), plant height (134.33 (cm,chlorophyll (74.37mg g^{-1})and total wheat yield (14.86 t ha^{-1}) compared to the, control treatment.

I. Introduction

Soil salinity poses an environmental challenge that threatens the sustainability of agricultural activity, especially in arid and semi-arid regions. This phenomenon arises from the interaction of harsh climatic conditions with poor agricultural land management. With the increasing severity of climate change, salinity has become a growing threat to global food security. Salinity leads to the deterioration of the physical and chemical properties of the soil. High salt concentrations damage soil structure, reduce its permeability, and inhibit the bioavailability of essential nutrients. Saline environments also create conditions that limit the vital activity of beneficial soil microorganisms. For plants, the main challenge is what is known as "physiological desiccation," which occurs when the high osmotic pressure in the soil solution prevents roots from absorbing water. In addition, the accumulation of ions, especially sodium and chloride, leads to direct ion poisoning, causing yellowing of leaves, stunted growth, and a significant decrease in yield (Bandak et al.,2024; Ali,2025).

Recent research has shown that conventional fertilizers often fail to produce satisfactory results in saline and calcareous soils, where nutrients are lost through leaching, volatilization, or chemical fixation. These failures not only reduce crop productivity but also increase environmental pollution (Zhang et al., 2025).

To mitigate these effects, innovative technologies such as nanomaterials have garnered significant attention. Nanoparticles offer highly efficient nutrient utilization due to their large surface area and high mobility. Silicon nanoparticles have emerged as a highly effective option, enhancing photosynthetic efficiency and stimulating antioxidant defense systems within plants. This enables crops to maintain good water balance and resist the dual stress of salinity and drought (Shkryl et al.,2024; Soliman et al.,2025). Meanwhile, biochar has emerged as a sustainable and environmentally friendly soil amendment. Biochar is characterized by its high resistance to degradation and its ability to improve the cation exchange capacity (CEC) of soils. By enhancing the soil's ability to retain water and nutrients, biochar helps mitigate salinity stress, increases chlorophyll content, and stimulates root growth, making it an essential tool for rehabilitating degraded lands (Mustafa et al.,2022; Gharred et al.,2022). These strategies are vital for strategic crops like wheat, which is a cornerstone of food security in regions such as Iraq. Wheat productivity in these areas is significantly affected by saline irrigation water, with crop losses reaching up to 20%. Therefore, the interweaving of

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silicon nanoparticles with biochar offers a promising synergistic approach to improving wheat productivity, and, more importantly, this integration supports the sustainable management of soil and water resources, ensuring stable agricultural production under increasing salinity conditions and environmental challenges (Tuama et al.,2024; Rehman et al.,2025).

II. Materials and Methods

StudySite and Soil Characteristics

The field study was conducted during the 2024-2025 growing season at the research station of the College of Agriculture, University of Basrah (Karma Ali area), located at latitude 30.57081°N and longitude 47.749870°E. Prior to the planting experiment, soil samples were collected from the topsoil at depths ranging from 0 to 30 cm. The samples were air-dried, then ground and thoroughly mixed to ensure homogeneity, and subsequently passed through a sieve with a 2.0 mm mesh size. Several physical and chemical measurements and analyses of the soil were performed before planting, according to the methods described in Page et al. (1982). The results are recorded in Table 1.

PlantGrowth Indicators

Plant samples were collected by taking a flag leaf from seven plants per experimental unit during the vegetative growth stage. The following indicators were estimated.

- **Chlorophyll**

The total chlorophyll concentration in the leaves (mg/g fresh weight) was estimated according to the Goodwin method (1976) as follows.0.5 g of fresh plant tissue was taken and crushed in a ceramic mortar with 10 mL of 80% acetone (prepared by adding 20 mL of distilled water to 80 mL of pure, concentrated acetone).The crushing was done in two batches: the first with 2 mL of acetone, followed by the addition of the remaining amount.The crushed tissue was centrifuged for 5 minutes. The light absorption of the pigment was measured using a UV spectrophotometer at two wavelengths: 663 nm (for chlorophyll a) and 645 nm (for chlorophyll b). The amount of pigment was then calculated using the following equation;

$$\text{Total chlorophyll} = [20.2 \times D(645) + 8.02 \times D(663)] \times (V / (W \times 1000))$$

:Where

D: Light absorption

D(663): Light absorption reading at 663 nm

D(645): Light absorption reading at 645 nm

V: Total volume of extract used (10 ml acetone)

W: Weight of soft tissue (0.5 g)

- **Plant Height**

The maximum height of ten plants, representing each experimental unit, wascalculated Average of these measurements.

- **Grain Yield**

After separating the grain from the straw, the grain was weighed using an electronic scaleand the grain yield was calculated in tons per hectare.

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- **Dry Weight**

After harvesting, the plants were dried in an oven at 65°C until a constant weight was reached, and the dry weight was then recorded.

ExperimentalDesign and Treatments

The experimental design was based on a randomized complete block design (RCBD) within a factorial (3x4) experiment framework, with three replicates per treatment, resulting in a total of 36 experimental units, each with an area of 4 m². Improved surface irrigation was used, and irrigation was carried out at the field capacity level. The experiment included two treatment levels: Biochar Application: This included three levels (0, 20, and 30 tons/hectare-1), where the material was mixed into the topsoil to a depth of 30 cm to ensure uniform distribution of the bio-amendment before planting. Nanosilicon (Nano-Si) fertilization: Four levels of silicon (0, 200, 300, and 400 kg/ha) were applied. The nano-silica compound was dissolved in the irrigation water, and the quantity was divided into two applications during the growing season. Wheat seeds (*Triticum aestivum L.*) of the "Research 22" variety were sown in rows, with 6 rows per experimental unit, spaced 20 cm apart, and at a depth of 5 cm.

Table (1) Some chemical and physical properties of field soil

<table>
<tr><th>unit</th><th>value</th><th>depth</th><th colspan="2">page</th></tr>
<tr><td>-</td><td>8.5</td><td>cm 30 -0</td><td colspan="2">Soil reactivity level Ph1:1</td></tr>
<tr><td>Ds m^{-1}</td><td>12</td><td>cm 30-0</td><td colspan="2">electrical conductivityEC</td></tr>
<tr><td>$Cmol^{+}Kg^{-1}$</td><td>34.27</td><td colspan="3">Positive ion exchange capacityCEC</td></tr>
<tr><td>g kg^{-1}</td><td>455</td><td colspan="3">Total solid carbonates</td></tr>
<tr><td>mg kg^{-1}</td><td>21.52</td><td colspan="3">Ready-made phosphorus</td></tr>
<tr><td>mg kg^{-1}</td><td>13.8</td><td colspan="3">Ready-made nitrogen</td></tr>
<tr><td>mg kg^{-1}</td><td>95.3</td><td colspan="3">Ready-made potassium</td></tr>
<tr><td>mg kg^{-1}</td><td>23.2</td><td colspan="3">Ready-made silicone</td></tr>
<tr><td rowspan="3">gkg^{-1}</td><td>400</td><td>sand</td><td rowspan="3">Weave
Clay Loam</td><td rowspan="3">particle size distribution of soil</td></tr>
<tr><td>204</td><td>silt</td></tr>
<tr><td>396</td><td>clay</td></tr>
<tr><td rowspan="2">Megagram m^3</td><td colspan="2">2.65</td><td colspan="2">True density</td></tr>
<tr><td colspan="2">1.65</td><td colspan="2">apparent density</td></tr>
<tr><td>%</td><td colspan="2">38</td><td colspan="2">Total porosity</td></tr>
</table>

III. Discussion

Plant height (cm)

The results of the statistical analysis (Table 2) showed statistically significant differences at the 0.05 level, as determined by the R.L.S.D. test, for the effects of adding biochar and nanosilica, and the interaction between them at different levels, on plant height. The maximum plant height (143.33 cm) was recorded at the highest application rate (30 t ha^{-1} of biochar + 400 kg ha^{-1} of nanosilica). The synergistic effect resulting from the interaction of nanosilica with biochar is attributed to the improvement in vegetative growth indices of the wheat crop, such as plant height and leaf area. Physiologically, nanocellulose enhances osmotic adjustment and improves gas exchange efficiency, thereby increasing photosynthetic rates and carbohydrate formation (Verma et al., 2021). Furthermore, the use of biochar contributes to improving the physical and chemical properties of the soil and increases the availability of nutrients (Adba'a et al., 2024). This effect is not limited to improving nutrient uptake, but extends to activating soil microorganisms and stimulating fundamental cellular processes such as cell division and elongation (Raza et al., 2023). As a result of this

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interaction, greater efficiency in water and nutrient uptake is achieved, which has positively contributed to increased plant height and the marked development of the vegetative mass (Zulfiqar et al., 2024).

chlorophyll concentration (mg g⁻¹)

The results of the statistical analysis (Table 2) showed significant differences ($P \geq 0.05$) in the effect of adding biochar and nanosilica, and their interaction at different levels, on chlorophyll concentration, with the concentration rising to 74.37 mg g^{-1} at the highest application rate (30 t ha^{-1} biochar + 400 kg ha^{-1} nanosilica) respectively. The results showed that silicon-treated biochar outperformed untreated biochar in enhancing plant performance, playing an important role in reducing the negative effects of salt stress and preventing chlorophyll degradation. This improvement is attributed to silicon's ability to regulate the activity of antioxidant enzymes, enhance nutrient uptake, and regulate soil pH, thereby creating an optimal root environment that supports plant growth (Gill et al., 2024; Ahmed et al., 2025). Furthermore, the interaction between nanocellulose and biochar improved the physical and chemical properties of the rhizosphere (root zone) and increased nutrient availability. This was directly reflected in the stability and synthesis of chlorophyll content even under water-stress conditions; a marked increase in carotenoid and chlorophyll (a and b) concentrations was recorded in drought-stressed plants, findings consistent with those reported by (Wahab et al., 2022; Waqar et al., 2022).

Dryweight of straw (tonnes ha^{-1})

The results of the statistical analysis (Table 2) showed significant differences at the 0.05 level according to the R.L.S.D. test for the effect of adding biochar and nanocellulose and their interaction at different levels on the dry weight of straw, where the weight increased to 21.26 tonnes ha^{-1} at the highest application rate (30 tonnes ha^{-1} biochar + 400 kg ha^{-1} nanosilica). The significant increase in the dry weight of the plant at the interaction between biochar and nanosilica is attributed to the improvement of soil properties and the enhancement of the plant's physiological performance. On the one hand, biochar increases cation exchange capacity (CEC) and improves porosity, thereby increasing the availability of nutrients such as nitrogen, phosphorus and potassium (Hafez et al., 2021). On the other hand, the physiological role of nanocellulose complements this improvement by regulating osmotic pressure, enhancing gas exchange efficiency, and increasing chlorophyll content and photosynthetic rates. This interaction leads to an abundance of metabolic products, which accelerates the rate of grain filling and increases biomass (Ahmed et al., 2025). This interaction also contributed to maintaining ionic balance (Na^+: K^+) under salt stress conditions, thereby protecting cell membranes from salt stress and providing the energy required for dry matter accumulation, which is directly reflected in the plant's dry weight (Shabbir et al., 2021; Zulfiqar et al., 2024).

Total wheat yield (t/ha)

The results of the statistical analysis (Table 2) showed significant differences at the 0.05 level according to the R.L.S.D. test for the effect of adding biochar and nanosilica and their interaction at different levels on wheat yield, where the yield increased to 14.86 tonnes ha^{-1} at the highest application rate (30 tonnes ha^{-1} biochar + 400 kg ha^{-1} nanosilica). Biochar plays a role in mitigating salt stress in wheat plants. Thanks to its highly porous structure, biochar acts as a natural filter, absorbing sodium and chloride ions and reducing osmotic pressure on the roots. It also improves the physicochemical properties of the soil, increasing the availability of potassium and calcium ions for absorption. This improved ionic balance protects vital plant functions from cytotoxicity, ultimately leading to increased plant height, grain count, and overall yield (Shahzadi et al., 2024). Nanosilica plays a complementary role in maintaining chlorophyll content and improving plant dry weight under stress. Nanosilica has a superior ability to regulate nutrient availability and ensure their gradual release due to its high surface area, providing sustainable plant nutrition that surpasses conventional fertilizers. This effect is clearly reflected in the crop's morphological characteristics, with increased grain filling efficiency, higher grain weight, and longer spikes (Sun et al., 2019; Ahmed et al., 2025). This intervention, which improves the physical and chemical properties of the soil and enhances the physiological response of the plant, has led to increased wheat productivity and ensured the quality of the final yield (Shabbir et al., 2021; Boora et al., 2023; Gill et al., 2024).

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Table (2) Effect of the Interaction between biochar and nano-silica on wheat plant growth indicators.

chlorophyll)mg g^{-1}(	Plant height)cm(	Weight of dry straw Ton $hectare^{-1}$	Total Result Ton $hectare^{-1}$	Nanosilica (Si) kg/$hectare^{1-}$	biochar)WSBC(ton $hectare^{-1}$
63.04	98.33	5.99	6.62	Si 1(0)	WSBC1(0)
69.49	105.67	8.46	7.99	Si 2(200)	
70.07	110.00	9.56	8.38	Si 3(300)	
70.42	111.67	10.19	8.83	Si 4(400)	
71.34	114.33	10.87	9.18	Si 1(0)	WSBC2(20)
71.88	117.33	11.13	9.57	Si 2(200)	
72.37	119.33	12.29	10.8	Si 3(300)	
72.89	121.67	13.58	11.32	Si 4(400)	
73.12	124.33	14.58	11.76	Si 1(0)	WSBC3(30)
73.61	127.33	16.02	12.45	Si 2(200)	
74.02	130.00	18.88	13.89	Si 3(300)	
74.37	134.33	21.26	14.86	Si 4(400)	
3.16**	1.99**	0.83**	0.59**	R.L.S.D (0.05)	

IV. Conclusion

1. The integration of biochar at a rate of 30 t ha^{-1} combined with nano-silica at 400 kg ha^{-1} represents the most effective treatment combination. This specific synergy resulted in the highest recorded values for total grain yield (14.86 t ha^{-1}) and dry straw weight (21.26 t ha^{-1}).
2. Nano-silica plays a fundamental role in elevating photosynthetic performance by mitigating chlorophyll degradation and stimulating its synthesis. Under maximum application levels, total chlorophyll content reached 74.37 mg g^{-1}, indicating improved light-harvesting capacity even under saline stress.
3. This synergistic strategy offers a robust solution for ensuring food security in arid regions, such as southern Iraq, where soil degradation and saline irrigation water significantly limit wheat productivity. The treatment functions by maintaining ionic balance and reducing the osmotic pressure exerted on the root system

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