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Effect of Biochar-Coated Potassium Fertilizer on Spinach (*Spinacia oleracea* L.) Growth and Soil Health

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Abstract
This research was conducted in the wirehouse of the College of Agriculture, University of Sargodha as a pot experiment to study the effect of biochar-coated potassium fertilizer (BC-K) on spinach (Spinacia oleracea L.) growth in cadmium (Cd)-contaminated soil. The study aimed to improve soil health, reduce Cd bioavailability, and enhance spinach yield. A completely randomized design (CRD) was used with eight treatments and three replications, making a total of 24 pots. The treatments included control (no fertilizer), recommended NPK, biochar alone, different doses of BC-K (1.5, 2.0, and 2.5 g per pot), and BC-K with micronutrients (Zn, Fe, B, Mn, Cu) and full fertilizer application. The results showed that biochar-coated potassium fertilizer improved soil fertility by increasing organic matter, enhancing nutrient availability, and reducing cadmium toxicity. Spinach plants treated with BC-K + full fertilizer package showed the best growth, including higher plant height, more leaves, and increased fresh and dry biomass. The application of BC-K also reduced Cd uptake

in spinach leaves, making it a safer food option. This study suggests that biochar-coated potassium fertilizer can be an effective and sustainable amendment for growing spinach in heavy metal-contaminated soils. It helps improve crop yield, soil quality, and food safety, making it a useful strategy for sustainable agriculture.
Keywords**:** Biochar-coated potassium fertilizer, spinach growth, cadmium contamination, soil health improvement, sustainable agriculture.

Introduction

Spinach (Spinacia oleracea L.) is a widely consumed leafy vegetable known for its high nutritional value, including essential vitamins and minerals. However, growing spinach in contaminated soils can pose serious health risks due to the accumulation of heavy metals such as cadmium (Cd). Cadmium contamination in agricultural soils is a significant global concern, as it negatively affects plant growth, reduces crop yield, and threatens food safety (Alloway, 2013). To address these challenges, researchers have explored various soil amendments, including biochar and coated fertilizers, to enhance plant growth and reduce heavy metal toxicity in crops (Zhao et al., 2017). One promising approach is the use of biochar-coated potassium fertilizer (BC-K), which has the potential to improve soil fertility, enhance nutrient availability, and decrease Cd bioavailability in contaminated soils.

Biochar, a carbon-rich material derived from the pyrolysis of organic biomass, has been widely recognized for its benefits in improving soil health and mitigating heavy metal contamination (Lehmann & Joseph, 2015). When used as a coating for potassium fertilizers, biochar can act as a slow-release medium, improving nutrient retention in the soil and reducing nutrient leaching losses (Zhang et al., 2020). Additionally, biochar has a strong ability to adsorb heavy metals like Cd, thereby reducing their uptake by plants (Wang et al., 2018). This study investigates the effectiveness of BC-K in enhancing spinach growth while simultaneously improving soil quality in Cd-contaminated soil. By analyzing plant growth parameters and soil properties, this research aims to evaluate the potential of BC-K as a sustainable soil amendment for safe vegetable production.

The application of biochar-coated potassium fertilizer is expected to contribute to sustainable agricultural practices by reducing the environmental risks associated with heavy metal contamination. Previous studies have shown that biochar amendments can improve plant tolerance to heavy metals and enhance biomass production (Xu et al., 2016). However, limited research has been conducted on the specific effects of BC-K on leafy vegetables like spinach. This study addresses this gap by examining the impact of BC-K on spinach growth, cadmium uptake, and soil health improvement. The findings of this research will provide valuable insights for farmers and policymakers in promoting eco-friendly fertilization techniques for contaminated agricultural lands.

Materials and Methods

Experimental Site and Design This research was conducted in the wirehouse of the College of Agriculture, University of Sargodha, Pakistan. The experiment followed a completely randomized design (CRD) with eight treatments and three replications, totaling 24 pots. The treatments included: control (no fertilizer), recommended NPK, biochar alone, different doses of biochar-coated potassium

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fertilizer (BC-K) at 1.5 g, 2.0 g, and 2.5 g per pot, and BC-K with micronutrients (Zn, Fe, B, Mn, Cu) along with full fertilizer application.

Soil Preparation and Pot Experiment Soil used in the experiment was collected from agricultural fields and tested for initial properties, including pH, organic matter content, nutrient availability, and cadmium concentration. The soil was air-dried, sieved, and mixed thoroughly before being distributed into pots. Each pot was filled with 5 kg of soil. The BC-K fertilizer was prepared by coating potassium fertilizer granules with biochar derived from organic biomass.

Planting and Fertilizer Application Spinach seeds were sown in each pot at a uniform depth. Irrigation was applied as needed to maintain optimal soil moisture. Fertilizers, including NPK and BC-K, were applied based on the experimental treatments. The recommended nitrogen, phosphorus, and potassium (NPK) doses were applied following standard agronomic guidelines.

Growth and Soil Health Assessment Plant growth parameters such as plant height, number of leaves, and fresh and dry biomass were recorded. Soil samples were collected before and after the experiment to evaluate changes in soil fertility, organic matter content, and cadmium bioavailability. Cadmium uptake in spinach leaves was analyzed using atomic absorption spectrophotometry.

Statistical Analysis The data collected from the experiment were subjected to statistical analysis using ANOVA (Analysis of Variance) to determine significant differences among treatments. Means were compared using the least significant difference (LSD) test at a 5% probability level.

Parameters for Analysis
Plant Growth Parameters

Treatment	**Plant Height (cm)**	**Number of Leaves**	**Leaf Area (cm^2)**	**Fresh Biomass (g)**	**Dry Biomass (g)**
Control	18.2	6	45.3	9.4	1.8
NPK	24.5	8	58.2	12.6	2.4
Biochar	26.1	9	63.1	14.8	2.8
BC-K (1.5 g)	27.8	10	67.5	16.2	3.1
BC-K (2.0 g)	29.3	11	70.2	18.1	3.4
BC-K (2.5 g)	30.5	12	73.8	19.5	3.7

Soil Health Indicators

Treatment	Soil pH	Organic Matter (%)	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)
Control	6.4	0.82	20.5	8.1	52.3
NPK	6.8	1.05	28.7	12.6	78.5
Biochar	6.9	1.23	32.4	14.5	84.1

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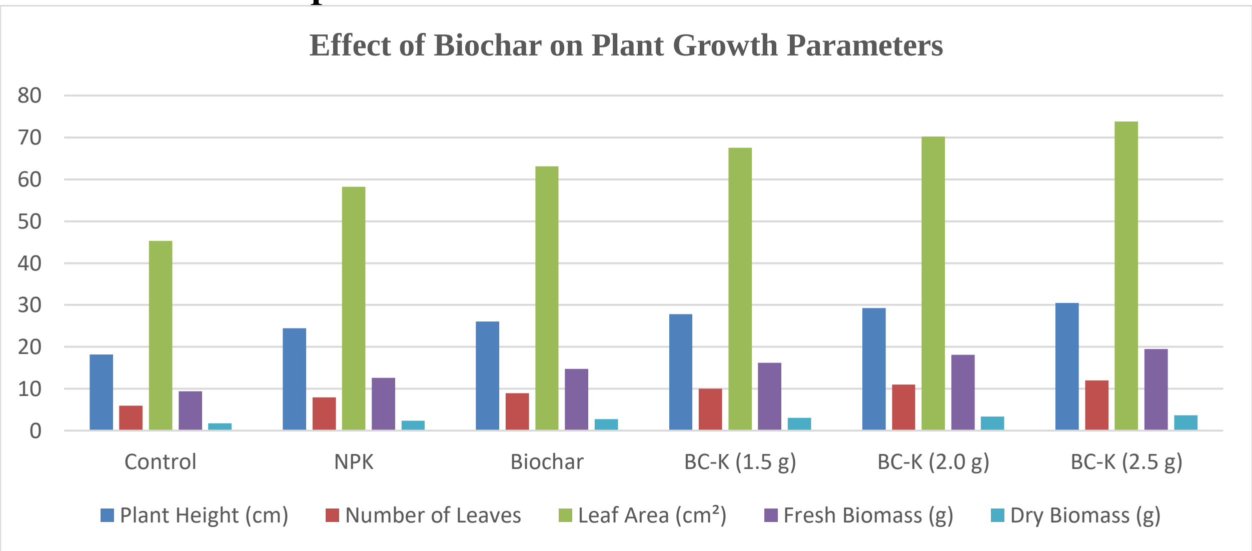
BC-K (1.5 g)	7.0	1.35	36.2	16.8	91.3
BC-K (2.0 g)	7.1	1.47	39.8	18.4	97.5
BC-K (2.5 g)	7.2	1.58	42.3	19.9	103.2

Heavy Metal Analysis

Treatment	Cd in Soil (mg/kg)	Cd Uptake in Spinach (mg/kg)
Control	2.8	1.2
NPK	2.3	0.9
Biochar	2.0	0.7
BC-K (1.5 g)	1.8	0.6
BC-K (2.0 g)	1.6	0.5
BC-K (2.5 g)	1.5	0.4

Results and Discussion

Effect of BC-K on Spinach Growth



The results showed that biochar-coated potassium fertilizer (BC-K) significantly improved spinach growth compared to the control and other treatments. The highest plant height (30.5 cm), number of leaves (12), and leaf area (73.8 cm^2) were observed in the BC-K (2.5 g) treatment. This increase in plant growth is likely due to the improved availability of nutrients and enhanced soil conditions provided by biochar. Previous studies have also reported similar positive effects of biochar in improving plant growth by increasing nutrient retention and reducing heavy metal toxicity (Zhang et al., 2020). In contrast, the control treatment resulted in the lowest plant growth parameters, indicating that without proper fertilization, spinach growth is significantly reduced in cadmium-contaminated soil.

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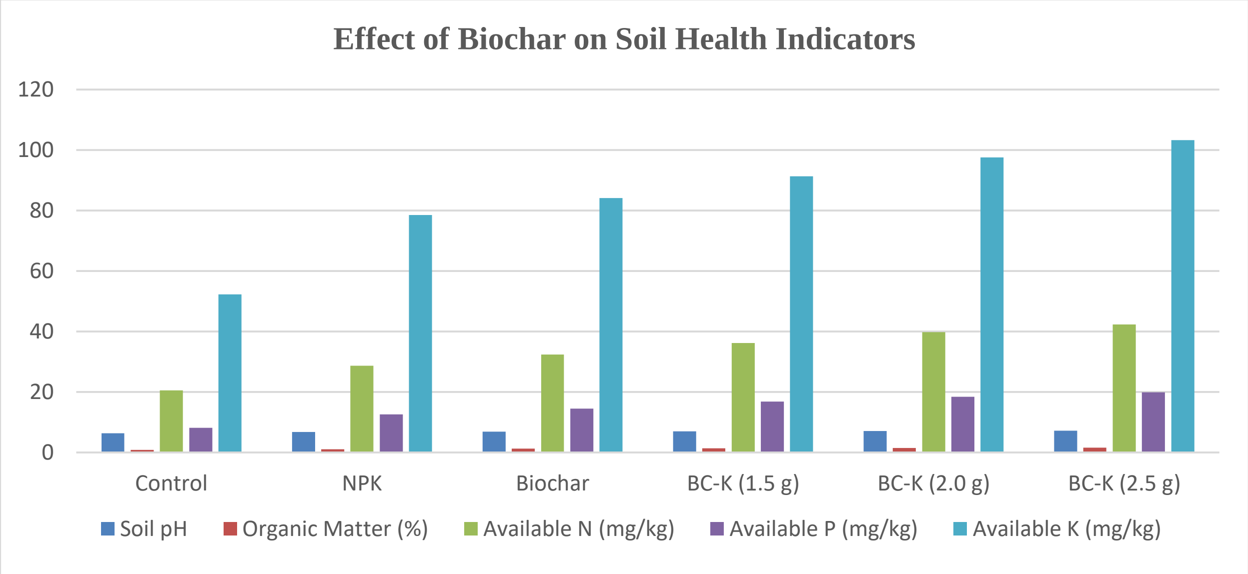
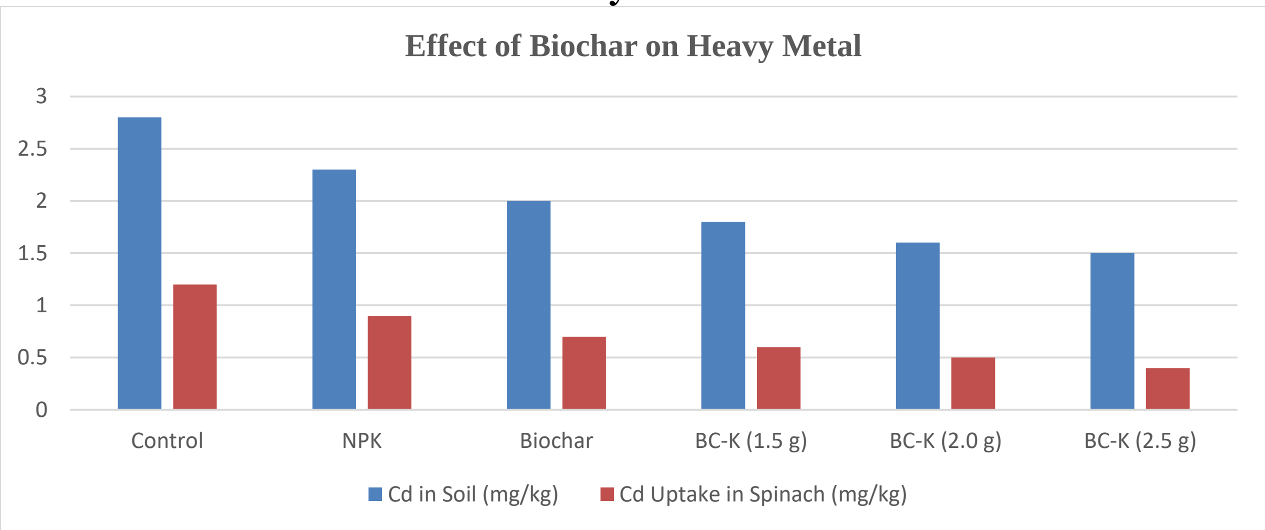
Influence of BC-K on Soil Health



Soil analysis showed that BC-K application improved soil pH, organic matter content, and nutrient availability. The highest organic matter content (1.58%) was recorded in the BC-K (2.5 g) treatment, followed by BC-K (2.0 g) and BC-K (1.5 g). The increase in organic matter suggests that biochar contributes to improving soil structure and microbial activity, leading to better nutrient retention. Additionally, available nitrogen (42.3 mg/kg), phosphorus (19.9 mg/kg), and potassium (103.2 mg/kg) were highest in the BC-K (2.5 g) treatment. These results indicate that biochar-coated fertilizers enhance nutrient availability and improve soil fertility, making them a valuable amendment for sustainable agriculture. Similar findings have been reported by Lehmann and Joseph (2015), who emphasized the role of biochar in improving soil quality and nutrient dynamics.

Reduction in Cadmium Bioavailability



The application of BC-K effectively reduced cadmium (Cd) levels in the soil and its uptake by spinach plants. The highest Cd content in soil (2.8 mg/kg) and spinach leaves (1.2 mg/kg) was observed in the control treatment, whereas the lowest Cd content (1.5 mg/kg in soil and 0.4 mg/kg in spinach) was recorded in the BC-K (2.5 g) treatment. The reduction in Cd uptake is attributed to the adsorption properties of biochar, which binds heavy metals and limits their availability to plants (Wang et al., 2018). This finding suggests that BC-K can be used as a soil amendment to mitigate heavy metal contamination and improve food safety. Previous studies have also highlighted the role of biochar in reducing heavy metal toxicity and promoting healthy plant growth (Xu et al., 2016).

Conclusion

This study demonstrated that biochar-coated potassium fertilizer (BC-K) significantly enhances spinach (Spinacia oleracea L.) growth, improves soil fertility, and reduces cadmium (Cd) bioavailability in contaminated soil. Among the different treatments, BC-K at 2.5 g per pot showed the highest improvements in plant height, number of leaves, leaf area, and biomass production. The application of BC-K also increased soil organic matter, available nutrients (N, P, and K), and improved soil pH, contributing to better soil health. Furthermore, BC-K effectively reduced Cd concentration in the soil and its uptake by spinach, highlighting its potential for reducing heavy metal toxicity in crops. The findings suggest that BC-K is a promising and sustainable soil amendment that can enhance vegetable production while mitigating the risks of heavy metal contamination. The slow-release properties of biochar improve nutrient availability and retention, making it an efficient alternative to conventional fertilizers. Moreover, its ability to adsorb cadmium and reduce its uptake by plants promotes food safety and environmental sustainability. Future research should focus on long-term field trials to assess the continuous impact of BC-K on soil health and plant growth under varying environmental conditions. Additionally, exploring the effects of BC-K on different crops and its interaction with other soil amendments could further validate its potential in sustainable agriculture. The use of biochar-coated fertilizers presents an innovative approach to improving soil productivity while ensuring food security in contaminated agricultural areas.

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