Dialogue Social Science Review (DSSR)
www.thedssr.com

ISSN Online: 3007-3154
ISSN Print: 3007-3146

DIALOGUE SOCIAL SCIENCE REVIEW

Vol. 3 No. 3 (March) (2025)

Enhancing Spinach (*Spinacia oleracea* L.) Growth and Soil Health Using Biochar-Coated Potassium Fertilizer

Masood Ahmed khan (Corresponding Author)
Masood.erabzai@gmail.com
Institute of Horticultural Sciences, University of Agriculture Faisalabad.

Muhammad Adnan Karim
adnankarim8011@gmail.com
Institute of Horticultural Sciences, University of Agriculture Faisalabad

Salma Malik
salma125malik@gmail.com
Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad

Muneeba Arooj
muneebaarooj786@gmail.com
Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad

Waseem Ahmed
Rindwab@gmail.com
Department of Soil Science, Sindh Agriculture University Tandojam

Asif Ali Mastoi
aamastoi@sau.edu.pk
Department of Soil Science Sindh Agriculture University Sub-Campus Umerkot

Muhammad Asif Khan
Asifkhan66544@gmail.com
Department of Forestry & Wildlife Management, The University of Haripur, Haripur Khyber Pakhtunkhwa 22620, Pakistan

Abstract
This study was carried out in the wirehouse of the College of Agriculture, University of Sargodha, using potted plants to test how biochar-coated potassium fertilizer (BC-K) affects spinach (Spinacia oleracea L.) growth in cadmium (Cd)-contaminated soil. The goal was to improve soil health, reduce Cd availability, and increase spinach yield. The experiment followed a completely randomized design (CRD) with eight treatments and three replications, making a total of 24 pots. The treatments included a 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 combined with micronutrients (Zn, Fe, B, Mn, Cu) and full fertilizer application. Results showed that BC-K improved soil fertility by increasing organic matter, making nutrients more available, and reducing Cd toxicity. Spinach plants treated with BC-K and full fertilizer had the best growth, with taller plants, more leaves, and higher fresh and dry weight. BC-K application also lowered Cd levels in spinach leaves, making it a safer food choice. This study suggests that biochar-coated potassium fertilizer is a

Dialogue Social Science Review (DSSR)
www.thedssr.com

ISSN Online: 3007-3154
ISSN Print: 3007-3146

DIALOGUE SOCIAL SCIENCE REVIEW

Vol. 3 No. 3 (March) (2025)

useful and eco-friendly way to grow spinach in polluted soils. It helps increase crop yield, improves soil quality, and enhances food safety, making it a good option for sustainable farming.
Keywords: Biochar-coated potassium fertilizer, spinach growth, cadmium contamination, soil health, sustainable agriculture.

Introduction

Spinach (*Spinacia oleracea L.*) is a popular leafy vegetable known for its high nutritional value, including essential vitamins and minerals (Zaib et al., 2023a; Bayar et al., 2024; Zeeshan et al 2024a). However, when grown in contaminated soil, spinach can absorb harmful heavy metals like cadmium (Cd) (Zaib et al., 2023b; Ge et al., 2024; Zeeshan et al., 2023a), which poses health risks. Cadmium contamination in agricultural soil is a serious global issue as it harms plant growth, reduces crop yield, and affects food safety (Alloway, 2013). To solve this problem, researchers have tested different soil treatments (Zaib et al., 2023c; Zubair et al., 2023a; Zeeshan et al 2023b), such as biochar and coated fertilizers, to improve plant growth and reduce heavy metal toxicity (Zhao et al., 2017; Zaib et al., 2023d; Zubair et al., 2023b; Zeeshan et al 2024b).

One promising method is using biochar-coated potassium fertilizer (BC-K), which can improve soil fertility (Zaib et al., 2023e; Abbas et al., 2023a; Zeeshan et al 2023c), increase nutrient availability (Zaib et al., 2023f; Abbas et al., 2023b; Zeeshan et al 2023d), and reduce Cd absorption by plants (Zaib et al., 2023g; Afzal et al., 2023a; Zeeshan et al 2023e). Biochar is a carbon-rich material made by heating organic matter without oxygen (Zaib et al., 2023h; Afzal et al., 2023b; Zeeshan et al 2024c). It is known for improving soil health and reducing heavy metal contamination (Lehmann & Joseph, 2015; Zaib et al., 2023i; Raza et al., 2023; Zeeshan et al 2023f). When biochar is used to coat potassium fertilizers (Zaib et al., 2023j; Aslam et al., 2024; Zeeshan et al 2024d), it helps release nutrients slowly (Zaib et al., 2023k; Iftikhar et al., 2023; Zeeshan et al 2023g), reducing nutrient loss and making them more available to plants (Zhang et al., 2020; Zaib et al., 2023l; Ali et al., 2023). Biochar also binds with heavy metals like Cd, preventing plants from absorbing them (Wang et al., 2018; Zaib et al., 2023m; Zeeshan et al 2024e).

This study examines how BC-K affects spinach growth and soil quality in Cd-contaminated soil. By measuring plant growth and soil properties, we aim to determine if BC-K is a sustainable solution for growing safer vegetables (Zaib et al., 2023n; Zaib, 2024a). Using biochar-coated potassium fertilizer could support sustainable agriculture by reducing environmental risks from heavy metal contamination (Zaib et al., 2023o; Zaib, 2024b). While past studies show that biochar improves plant resistance to heavy metals and boosts plant growth (Xu et al., 2016; Zaib et al., 2023p; Zaib and Adnan, 2024), little research has focused on how BC-K affects leafy vegetables like spinach (Zaib et al., 2023q; Zaib et al., 2024). This study fills that gap by investigating its impact on spinach growth, Cd uptake, and soil improvement (Zaib et al., 2023r; Zaib et al., 2023s). The results will help farmers and policymakers adopt eco-friendly fertilization methods for polluted farmlands.

Materials and Methods

Experimental Site and Design

Dialogue Social Science Review (DSSR)
www.thedssr.com

ISSN Online: 3007-3154
ISSN Print: 3007-3146

DIALOGUE SOCIAL SCIENCE REVIEW

Vol. 3 No. 3 (March) (2025)

This study was conducted in the wirehouse of the College of Agriculture, University of Sargodha, Pakistan. The experiment used a completely randomized design (CRD) with eight treatments and three replications, making a total of 24 pots. The treatments included:

- Control (no fertilizer)
- Recommended NPK fertilizer
- Biochar alone
- Biochar-coated potassium fertilizer (BC-K) at 1.5 g, 2.0 g, and 2.5 g per pot
- BC-K with added micronutrients (Zn, Fe, B, Mn, Cu) along with full fertilizer application

Soil Preparation and Pot Experiment

Soil was collected from agricultural fields and tested for properties such as pH, organic matter, nutrient levels, and cadmium (Cd) concentration. It was then air-dried, sieved, and thoroughly mixed before being placed in pots (5 kg soil per pot). The BC-K fertilizer was prepared by coating potassium fertilizer granules with biochar made from organic materials.

Planting and Fertilizer Application

Spinach seeds were sown in each pot at the same depth. Water was applied as needed to maintain proper soil moisture. Fertilizers (NPK and BC-K) were added according to the experimental treatments, following standard agronomic recommendations.

Growth and Soil Health Assessment

Plant growth was measured by recording plant height, number of leaves, and fresh and dry weight. Soil samples were taken before and after the experiment to check for changes in fertility, organic matter, and cadmium availability. Cadmium levels in spinach leaves were tested using atomic absorption spectrophotometry.

Statistical Analysis

The collected data were analyzed using ANOVA (Analysis of Variance) to find significant differences between treatments. The least significant difference (LSD) test at a 5% probability level was used to compare treatment means.

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

Dialogue Social Science Review (DSSR)
www.thedssr.com

ISSN Online: 3007-3154
ISSN Print: 3007-3146

DIALOGUE SOCIAL SCIENCE REVIEW

Vol. 3 No. 3 (March) (2025)

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

Dialogue Social Science Review (DSSR)
www.thedssr.com

ISSN Online: 3007-3154
ISSN Print: 3007-3146

DIALOGUE SOCIAL SCIENCE REVIEW

Vol. 3 No. 3 (March) (2025)

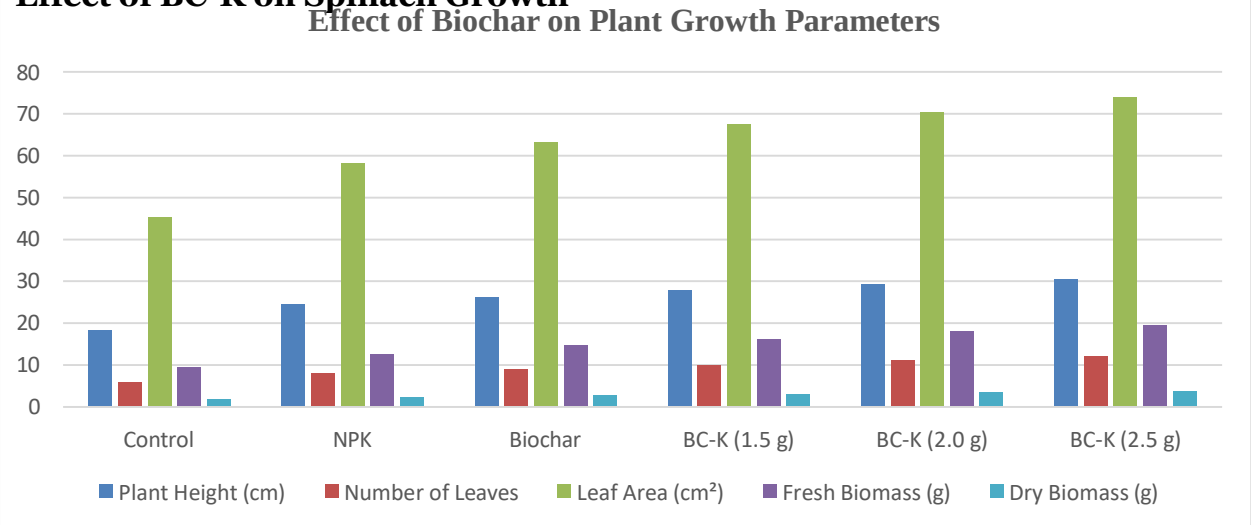
BC-K (1.5 g)	7.0	1.35	36.2	16.8	91.3
BC-K (2.0 g)	7.1	1.47	39.8	18.4	97.5
BC-K (2.5 g)	7.2	1.58	42.3	19.9	103.2

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



Results (Simplified Version)

The results showed that biochar-coated potassium fertilizer (BC-K) significantly improved spinach growth compared to the control and other treatments. The best growth was recorded in the BC-K (2.5 g) treatment, where spinach plants had the highest plant height (30.5 cm), the most leaves (12), and the largest leaf area (73.8 cm²). This improvement is likely due to better nutrient availability and improved soil conditions provided by biochar. Previous studies have also found that biochar helps plants grow by retaining nutrients and reducing heavy metal toxicity (Zhang et al., 2020). On the other hand, the control treatment (no fertilizer) had the poorest plant growth, showing that spinach struggles to grow in cadmium-contaminated soil without proper fertilization.

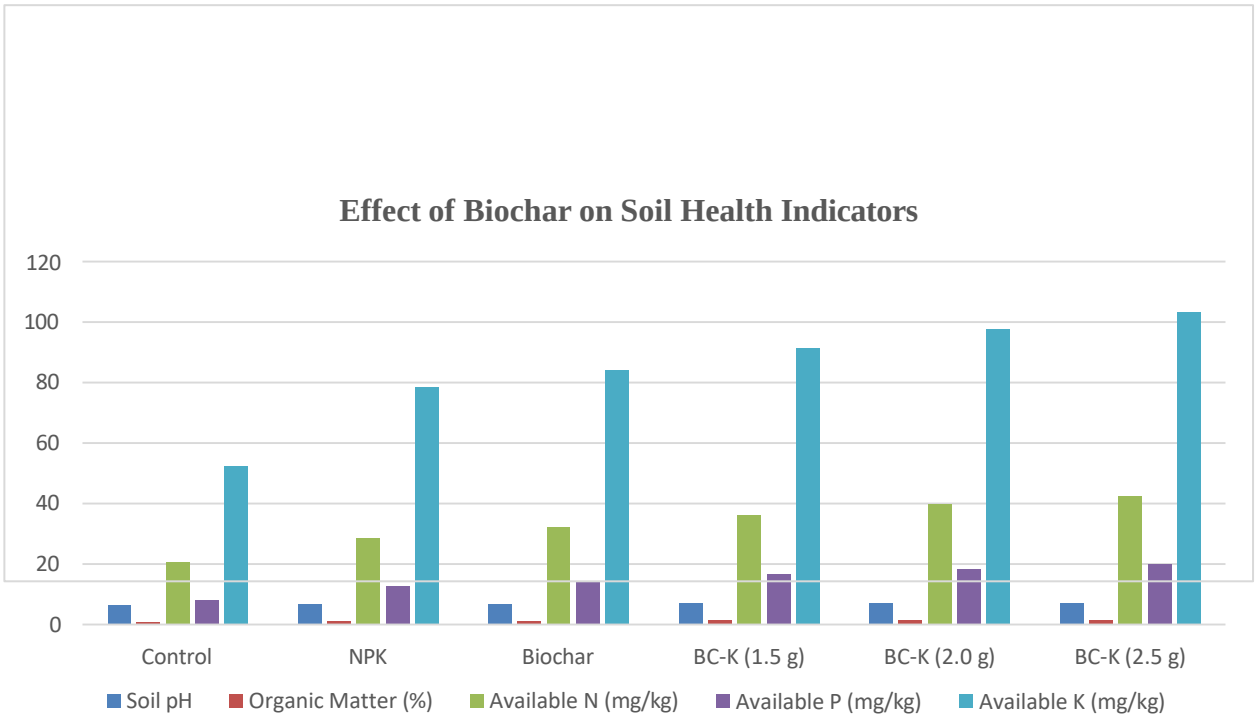
Dialogue Social Science Review (DSSR)
www.thedssr.com

ISSN Online: 3007-3154
ISSN Print: 3007-3146

DIALOGUE SOCIAL SCIENCE REVIEW

Vol. 3 No. 3 (March) (2025)

Influence of BC-K on Soil Health



Soil Analysis

Soil testing showed that using biochar-coated potassium fertilizer (BC-K) improved soil pH, organic matter, and nutrient availability. The highest organic matter content (1.58%) was found in the BC-K (2.5 g) treatment, followed by BC-K (2.0 g) and BC-K (1.5 g). This suggests that biochar helps improve soil structure and supports beneficial microbial activity, leading to better nutrient retention. The highest levels of available nitrogen (42.3 mg/kg), phosphorus (19.9 mg/kg), and potassium (103.2 mg/kg) were also recorded in the BC-K (2.5 g) treatment. These findings indicate that biochar-coated fertilizers enhance soil fertility and nutrient availability, making them a useful tool for sustainable farming. Similar results were reported by Lehmann and Joseph (2015), who highlighted biochar's role in improving soil quality and nutrient balance.

Reduction in Cadmium Bioavailability

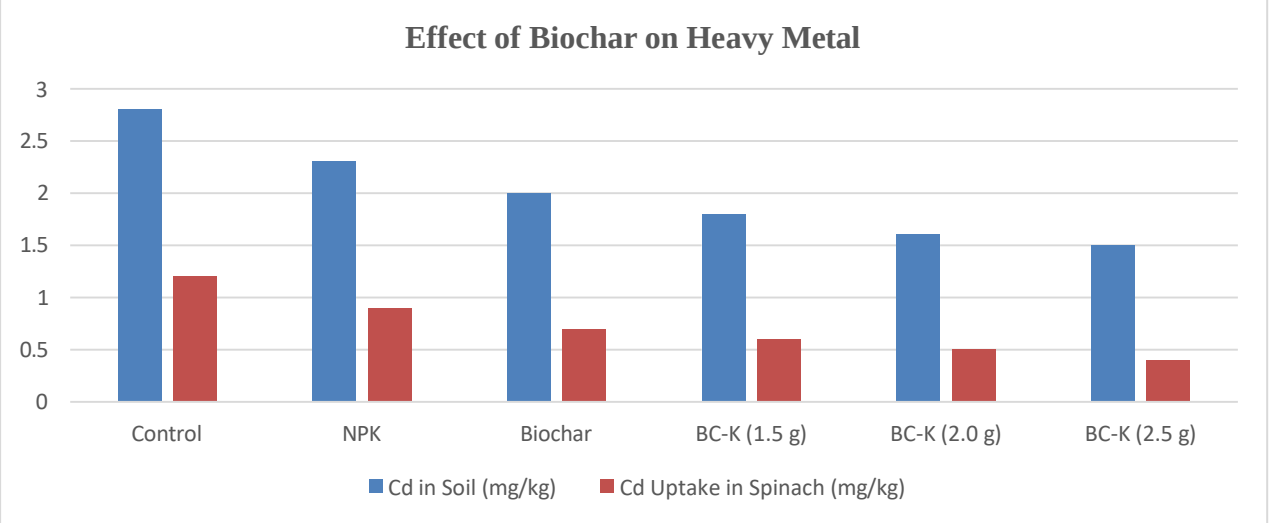
The application of biochar-coated potassium fertilizer (BC-K) significantly reduced cadmium (Cd) levels in the soil and its uptake by spinach plants. The highest Cd concentration in soil (2.8 mg/kg) and spinach leaves (1.2 mg/kg) was recorded in the control treatment, whereas the lowest levels (1.5 mg/kg in soil and 0.4 mg/kg in spinach) were observed in the BC-K (2.5 g) treatment. The reduction in Cd uptake is attributed to the strong adsorption properties of biochar, which binds heavy metals and limits their bioavailability to plants (Wang et al., 2018). These findings suggest that BC-K can serve as an effective soil amendment for mitigating heavy metal contamination and improving food safety. Previous studies have also highlighted biochar's role in reducing heavy metal toxicity and promoting healthier plant growth (Xu et al., 2016).

Dialogue Social Science Review (DSSR)
www.thedssr.com

ISSN Online: 3007-3154
ISSN Print: 3007-3146

DIALOGUE SOCIAL SCIENCE REVIEW

Vol. 3 No. 3 (March) (2025)



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 greatest improvements in plant height, number of leaves, leaf area, and biomass production. Additionally, BC-K application increased soil organic matter content, enhanced nutrient availability (N, P, and K), and optimized soil pH, thereby improving overall soil health. Furthermore, BC-K effectively reduced Cd concentrations in the soil and its uptake by spinach, emphasizing its potential for mitigating heavy metal toxicity in crops. The slow-release properties of biochar improve nutrient retention and availability, making it a sustainable alternative to conventional fertilizers. Moreover, its ability to adsorb cadmium and minimize its accumulation in edible plant parts enhances food safety and environmental sustainability. Future research should focus on long-term field trials to assess the sustained impact of BC-K under different environmental conditions. Additionally, investigating its effects on other crops and its interactions with various soil amendments could further validate its potential in sustainable agriculture. The use of biochar-coated fertilizers presents an innovative strategy for improving soil productivity and ensuring food security in contaminated agricultural areas.

References

Alloway, B. J. (2013). Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability. Springer Science & Business Media.

Lehmann, J., & Joseph, S. (2015). Biochar for environmental management: Science, technology and implementation. Routledge.

Wang, H., Gao, B., Fang, J., Ok, Y. S., Xue, Y., & Yang, K. (2018). Engineered biochar for environmental applications. Critical Reviews in Environmental Science and Technology, 48(1), 1-50.

Xu, X., Zhao, Y., Sima, J., Zhao, L., Mašek, O., & Cao, X. (2016). Indispensable role of biochar-inherent mineral constituents in its environmental

applications: A review. Bioresource Technology, 215, 318-327.

Abbas, Roaid & Zaib, Muhammad & Haider, Kamran & Ali, Malik & Abbasi, Raza & Hassan, Muhammad Haseeb & Khan, Muhammad & Nawaz, Muhammad & Abbas, Zaheer & Khalid, Muhammad & Sidra, & Nasir, Awon & Muneeb Hassan, Muhammad. (2023a). Remediation of Heavy Metal Contaminated Sites by Application of Biochar: A Review with Future Prospects. International Journal of Scientific Research and Engineering Development 05. 59-79.

Abbas, Zaheer & Zaib, Muhammad & Bayar, Jalal & Sidra,. (2023b). Effects of Cover Crops on Soil Physical Properties: A Comprehensive Review. International Journal of Scientific Research and Engineering Development. 05. 261-290.

Afzal, Abdul & Zubair, Hassan & Abid, Shahzad & Shahzaib, Muhammad & Hassan, Muhammad Haseeb & Khalid, Sarmad & Shoaib, Muhammad & Ahmad, Aziz & Zaib, Muhammad. (2023a). Impacts of Water Logging on Soil Microbial Intentions and Mung Bean (Vigna radiata L.) Physiology. Indian Journal of Pure & Applied Biosciences. 11. 68-79. 10.18782/2582-2845.9036.

Afzal, Abdul & Zubair, Hassan & Ali, Umar & Nawaz, Mudassar & Mansoor, Ayesha & Zaib, Muhammad & Marium, Aiza. (2023b). Mechanisms of Disease Resistance in Plants For Sustainable Agriculture. 4. 1-13. 10.18782/2582-7146.207.

Ali, Shahzad & Zaib, Muhammad & Zubair, Hassan & Afzal, Abdul & Zehra, Emaan & Ashraf, Muhammad & Farooq, Muhammad & Ahmad, Muhammad & Asif, Hamza & Marium, Aiza. (2023). Ecological Restoration of Degraded Lands. 4. 25-34. 10.18782/2582-7146.205.

Aslam S, Mansoor M, Bano S, Zeeshan A, Ilyas A, Eman A, et al. Ethnoveterinary Study of Medicinal Plants of District Okara, Pakistan. Journal of Health and Rehabilitation Research. 2024; 4(2):963-970.

Bayar, Jalal & Ali, Nawab & Dong, Younsuk & Ahmed, Uzair & mehran anjum, Muhammad & Khan, Gul & Zaib, Muhammad & Jalal, Arshad & Ali, Rovaid. (2024). Biochar-based adsorption for heavy metal removal in water: a sustainable and cost-effective approach. Environmental Geochemistry and Health. 46. 428. 10.1007/s10653-024-02214-w. (Bayar et al., 2024)

Ge, Shiji & Zhiqiang, Jiao & Gao, Chenyang & Zaib, Muhammad & Ruan, Xinling & Wang, Yangyang. (2024). Potential Health Risks for Long-Term Stays in Underground Parking Garages: Implications of Polycyclic Aromatic Hydrocarbons in Surface Dust. Indoor Air. 2024. 5527710. 10.1155/2024/5527710.

Iftikhar A, Aijaz N, Farooq R, Aslam S, Zeeshan A, Munir M, et al. Beneficial Role of Phosphate Solubilizing Bacteria (PSB) In Enhancing Soil Fertility Through A Variety of Actions on Plants Growth and Ecological Perspective: An Updated Review. Journal of Xi'an Petroleum Institute (Natural Science Edition). 2023; 19(9):520-547.

Raza, Irfan & Zubair, Muhammad & Zaib, Muhammad & Khalil, Muhammad Hamza & Haidar, Ali & Sikandar, Asma & Abbas, Muhammad Qamer & Javed, Ahsan & Liaqat, Muhammad & Ain, Arisha & Nafees, Muhammad & Ashfaq, Muhammad. (2023). Precision Nutrient Application Techniques to

ISSN Online: 3007-3154
ISSN Print: 3007-3146

Vol. 3 No. 3 (March) (2025)

Improve Soil Fertility and Crop Yield: A Review with Future Prospect. International Research Journal of Education and Technology. 05. 109-123.

Shaukat S, Zeeshan A. Application of Floating Wetland for Treatment of Paper Mill Wastewater. Journal of Plantarum. 2023; 5(1):69-86. (Shaukat and Ali, 2023)

Zaib, M. & Adnan, M. (2024). Phytoremediation: A Comprehensive Look at Soil Decontamination Techniques. International Journal of Contemporary Issues in Social Sciences. 3(1), 998-1029.

Zaib, M. (2024b). Boron Nutrient for Sustainability of Plant Growth and Soil Health: A Review with Future Prospects. International Journal of Contemporary Issues in Social Sciences. 3(1), 912-931.

Zaib, M., Abbas, Q., Hussain, M., Mumtaz, S., Khalid, M., Raza, I., Abbas, S., Danish, M., Abbas, R., Muhammad, N. & Bano, S. (2023a). Micronutrients and Their significance in Agriculture: A Mini Review with Future Prospects Corresponding Author address. International Research Journal of Education and Technology. 05(04), 234-252.

Zaib, M., Aryan, M. & Ullah, H. (2023b). Innovative Inorganic Pollutant Bioremediation Approaches for Industrial Wastewater Treatment: A Review. International Journal of Scientific Research and Engineering Development. 6(4), 1294-1304

Zaib, M., Farooq, U., Adnan, M., Abbas, Z., Haider, K., Khan, N., Abbas, R., Nasir, A., Sidra., Muhay-Ul-Din, M., Farooq, T., & Muhammad, A. (2023d). Optimization water stress in crop plants, implications for sustainable agriculture: current and future prospects. Journal of Environmental & Agricultural Sciences. 25 (1&2), 37-50.

Zaib, M., Raza, I., Zubair, M., Arif, Z., Mumtaz, M., Abbas, M.Q., Javed, A., Salman, S., Sikandar, A., Kashif, M., Muneeb, M. & Uzair, M. (2023g). Nano-Enabled Soil Amendments for Improved Soil Structure and Water Holding Capacity: An In-depth Review. International Research Journal of Education and Technology. 05(08), 344-357.

Zaib, M., Sandhu, M., Zar, M., Ghani, U., Rehman, A., Musharraf, M., Zubair, M., Abbas, R. & Raza, I. (2023h). A Brief Review on Plant Growth Promoting Rhizobacteria (PGPR): A Key Role in Plant Growth. International Research Journal of Education and Technology. 05(07), 104-126.

Zaib, M., Zeeshan, A., Akram, H., Amjad, W., Aslam, S. & Qasim, S. (2023i). Impact of Climate Change on Crop Physiology and Adaptation Strategies: A Review. International Research Journal of Education and Technology. 05(08), 15-38. (Zaib et al., 2023i)

Zaib, M., Zeeshan, A., Akram, H., Amjad, W., Bano, S., Aslam, S., Qasim, S., Faiz, S., Nazar, A. & Nazim, F. (2023k). Innovative Approaches Utilizing Plant-Based Techniques for Soil Conservation: An In-depth Review. International Research Journal of Education and Technology. 05(08), 319-330.

Zaib, M., Zeeshan, A., Akram, H., Hameed, S., Wakeel, A., Qasim, S. & Aslam, S. (2023l). Soil Contamination and Human Health: Exploring the Heavy Metal Landscape: A Comprehensive Review. Journal of Health and Rehabilitation Research. 3(2), 351-356. DOI: 10.61919/jhrr.v3i2.123

Zaib, M., Zeeshan, A., Aslam, S., Bano, S., Ilyas, A., Abbas, Z., Nazar, A. &

Dialogue Social Science Review (DSSR)
www.thedssr.com

ISSN Online: 3007-3154
ISSN Print: 3007-3146

DIALOGUE SOCIAL SCIENCE REVIEW

Vol. 3 No. 3 (March) (2025)

Mumtaz, S. (2023m). Drought Stress and Plants Production: A Review with Future Prospects. International Journal of Scientific Research and Engineering Development. 06(04), 1278-1293.

Zaib, M., Zubair, H., Afzal, A., Naseem, M., Maryam, D., Batool, S., Raza, S., Umar, M., Marium, A. & Tariq, H. (2023n). Biofortification for Enhancement of Micronutrient Contents in Cereals. Ind. J. Pure App. Biosci. 11(6), 53-67. DOI: http://dx.doi.org/10.18782/2582-2845.9035

Zaib, M., Zubair, M., Aryan, M., Abdullah, M., Manzoor, S., Masood, F. & Saeed, S. (2023p). A Review on Challenges and Opportunities of Fertilizer Use Efficiency and Their Role in Sustainable Agriculture with Future Prospects and Recommendations. Curr. Rese. Agri. Far. 4(4), 1-14. doi: http://dx.doi.org/10.18782/2582-7146.201

Zaib, M., Zubair, M., Mumtaz, S., Shaheen, C., Muqaddas, A., Sarwar, R., Noman, M., Irfan, M., Aman, Z., Hanan, A. & Sajid, S. (2023q). Trace Elements Behavior in Salt-Affected Soils: A Review. International Journal of Scientific Research and Engineering Development. 06(05), 73-81.

Zaib, M., Zubair, M., Rani, M., Nawaz, S., Haider, W., Shafiq, M., Cheema, Q., Shabbir, U., Nawaz, H. & Noor, M (2023r). In-Situ Remediation Strategies to Treat Polluted Water: A Review. International Research Journal of Education and Technology. 05(08), 331-343.

Zaib, Muhammad & Aryan, Muhammad & Khaliq, Adnan & Haider, Kamran & Ahmad, Safwan & Zeeshan, Ali & Haq, Ul & Ahmad, Umair & 候哥, Hussain & Zubair, Hassan. (2023c). Essential Insights for Effective Environmental Management and Human Well-being: Strategies for Remediation in Soil-Plant- Environment Systems.

Zaib, Muhammad & Farooq, Umer & Adnan, M & Sajjad, Shammaz & Abbas, Zaheer & Haider, Kamran & Khan, N & Abbas, R & Nasir, A. (2023e). Remediation of Saline Soils by Application of Biochar: A Review. Journal of Agriculture and Environmental Sciences. 04. 29-36.

Zaib, Muhammad & Ibrahim, Muhammad & Aryan, Muhammad & Mustafa, Raheel & Zubair, Muhammad & Mumtaz, Sana & Hussain, Tasawar. (2023f). Long-Term Efficacy of Biochar-Based Immobilization for Remediation of Heavy Metal-Contaminated Soil and Environmental Factors Impacting Remediation Performance. 6. 58-72.

Zaib, Muhammad & Muneeb Hassan, Muhammad & Hassan, Muhammad Haseeb & Zeeshan, Ali. (2024). SOIL MICROBES AND HUMAN HEALTH: A COMPREHENSIVE REVIEW. 3. 939-951.

Zaib, Muhammad & Zeeshan, Ali & Akram, Humaira & Amjad, Waheed & Bano, Sadaf & Aslam, Saira & Qasim, Samreen & Faiz, Sidra & Nazar, Aquib & Nazim, Farah. (2023j). Innovative Approaches Utilizing Plant-Based Techniques for Soil Conservation: An In-depth Review. 05. 319-330.

Zaib, Muhammad & Zubair, Hassan & 候哥, Hussain & Zahra, Maryam & Ali, Umar & Afzal, Abdul & Marium, Aiza. (20230). Emerging Trends in Biofortification for Microelement Enrichment in Crop Edibles: Implications for Health. 4. 15-24. 10.18782/2582-7146.204.

Zaib, Muhammad. (2024a). BIOFORTIFICATION: BRIDGING THE NUTRIENT GAP IN CHINESE AGRICULTURAL PRACTICES. 3. 902-911.

Zeeshan A, Abbas M, Qasim S, Nawaz L, Najam M, Waqas M, Zubair M, et al. Addressing Nutrient Deficiencies Through Zinc Biofortification. Emerging

Trends in Sustainable Agriculture. 2024a; 95-146.

Zeeshan A, Akram H, Ilyas A, Niaz S, Nazar A, Shakeel Y. Solanum Nigrum Linn: An Analysis of the Therapeutic Properties of Plant. Journal of Pure and Applied Agriculture. 2023a; 8(4):1-10.

Zeeshan A, Akram H, Nasir A, Manzoor S. Historical Significance and Modern Applications of Turmeric (Curcuma Longa) in Traditional Medicine and Beyond. International Research Journal of Educational Technology. 2023b; 5(11):113-123.

Zeeshan A, Akram H, Nazar A, Shoukat A, Pearl C, Nazim F, et al. Medicinal Importance of Ginger (Zingiber Officinale): A Systematic Review. GU Journal of Phytosciences. 2024b; 4(1):331-342.

Zeeshan A, Akram H, Qasim S, Naseer A, Nazar F, Rafique O. The Healing Touch of Foeniculum Vulgare Mill. (Fennel): A Review on Its Medicinal Value and Health Benefits. Journal of Health and Rehabilitation Research. 2023c; 3(2):793-800.

Zeeshan A, Amjad W, Akram H, Mobeen N, Qasim S, Naseer A, et al. Assessment of Nursery Administration and Identification of Ornamental Plant Species: A Case Study of Tehsil Pattoki (Pakistan). Journal of Asian Development Studies. 2023d; 12(4):468-480.

Zeeshan A, Amjad W, Faiz S, Noor M, Akram W, Yameen I, et al. Medicinal Importance of Solanum Nigrum Linn; A Review. Journal of Plant and Environment. 2023e; 5(2):181-189.

Zeeshan A, Amjad W, Masood M, Akram W, Yameen I, Mansoor M, et al. Neem's Bioactive Marvels: A Therapeutic Review. Journal of Health and Rehabilitation Research. 2024c; 4(1):185-195.

Zeeshan A, Hafeez UB, Abdullah M, Saeed S, Tariq MH, Abbas M, et al. The Controversy Surrounding Water Use and Its Implications for Crop Production: A Review with Current and Future Directions. International Research Journal of Educational Technology. 2023f; 5(10):336-351.

Zeeshan A, Munir MA, Sadia S. Unlocking the Promise of the ″Miracle Tree″: A Review on Therapeutic Applications and Phytochemistry of Moringa Oleifera L. Journal of Bioresource Management. 2024d; 11(1):102

Zeeshan A, Nazar A, Akram H, Hafeez I, Tariq A, Ali G, et al. Parthenium Hysterophorus L: A Review of Its Phytochemical, Biological and Therapeutical Applications. Lahore Garrison University Journal of Life Sciences. 2023g; 7(3):281-302.

Zeeshan A, Waqas M, Ramzan M, Ghafoor F, Usama I, Ibrahim M, et al. Narrative Review From Fields to Families: Understanding the Health Impacts of Excessive Soil Fertilization. Journal of Health and Rehabilitation Research. 2024e; 4(2):990-995.

Zeeshan, A., & Zaib, M., Ahmad, S., Akram, H. & Qasim, S. (2023). Diversity of Weeds in Rose Field in District Kasur Punjab Pakistan. Int. J. Adv. Res. Sci. Technol. 12(09), 1122-1132.

Zhang, P., Sun, H., Yu, L., & Sun, T. (2020). Adsorption and immobilization of heavy metals by biochar and biochar-based composites: A review. Environmental Pollution, 256, 113609.

Zhao, L., Cao, X., Masek, O., & Zimmerman, A. (2017). Heterogeneity of biochar properties as a function of feedstock sources and production temperatures. Journal of Hazardous Materials, 256, 1-9.

Dialogue Social Science Review (DSSR)
www.thedssr.com

ISSN Online: 3007-3154
ISSN Print: 3007-3146

DIALOGUE SOCIAL SCIENCE REVIEW

Vol. 3 No. 3 (March) (2025)

Zubair, Hassan & Afzal, Abdul & Shahid, Muhammad & Ali, Umar & Iftikhar, Hafiz & Abuzar, Ali & Zaib, Muhammad & Marium, Aiza. (2023). Historical Overview of the Chinese Agricultural Sciences and Technological Development. 4. 35-45. 10.18782/2582-7146.206.

Zubair, M., Raza, I., Batool, Y., Arif, Z., Muneeb, M., Uzair, M., Haidar, A., Zaib, M., Ashfaq, M., Akbar, H., Abbas, Q. & Ali, A. (2023b). A Review of Remediation Strategies against Arsenic (As) Removal from Groundwater by Using Different Filtration Techniques. Curr. Rese. Agri. Far. 4(3), 1-14. doi: http://dx.doi.org/10.18782/2582-7146.192