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Agricultural Consideration of the Effects of Biofertilizers and Boron on Desertified Soils: A Sustainable Strategy for Enhancing Soil Chemical Properties

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Abstract

This study explored a practical approach to restoring degraded agricultural soils in Iraq›s arid regions by combining biofertilizers (Azotobacter chroococcum and Bacillus megaterium) with boron supplementation. Conducted over 120 days using a randomized complete block design with four treatments: control, biofertilizer alone, boron alone, and a biofertilizer-boron combination, the research aimed to improve soil health and provide tangible benefits for farmers facing infertile, desertified lands. Results showed that the combined treatment improved soil properties, reducing pH from 8.40 ± 0.05 to 8.20 ± 0.06 and electrical conductivity (EC) from 3.10 ± 0.08 to 2.80 ± 0.09 dS m^{-1} ($P < 0.05$), while increasing organic carbon from 0.30 ± 0.02% to 0.50 ± 0.04%, nitrogen (N) from 33 ± 2.0 to 58 ± 3.0 mg/kg, phosphorus (P) from 5.0 ± 0.3 to 11.0 ± 0.6 mg/kg, potassium (K) from 82 ± 3.5 to 90 ± 4.5 mg/kg, and boron (B) from 0.20 ± 0.02 to 1.10 ± 0.06 mg/kg (all mean ± SE, n = 3, $P < 0.05$). Using biofertilizers together with boron-enhanced soil fertility more effectively than either treatment alone. This approach offers farmers a low-cost, environmentally friendly method to improve crop growth and restore soil health. The observed improvements over 120 days demonstrate that even short-term interventions can support agricultural productivity, enhance soil quality, and help communities adapt to desertification. Long-term monitoring is recommended to confirm the sustainability of these benefits.

Keywords: *Soil Chemical Properties, Biofertilizers, Boron, Sustainable Agriculture, Desertified Soils, Nutrient Dynamics.*

1. Introduction

Desertification is a major environmental issue, characterized by the deterioration of dryland ecosystems due to human activities and climate fluctuations. According to the United Nations Convention to Combat Desertification (UNCCD, 2020), more than one-third of the Earth›s land area is affected by desertification, threatening the livelihoods of over a billion people living in these regions. Soils in these areas suffer from low organic matter, nutrient deficiencies, increased salinity, and unstable pH levels. These conditions not only reduce agricultural productivity but also impair essential soil functions, such as nutrient cycling and water retention, thereby complicating efforts to sustainable land management (Lal, 2015; Smith et al., 2019).

The use of chemical fertilizers to improve soil fertility in degraded lands raises sustainability concerns due to environmental impacts, including groundwater pollution, soil acidification, and long-term degradation (Johnson, 2021). Excessive fertilizer use also decreases soil biodiversity and overall soil health, highlighting the need for more sustainable alternatives (Tilman et al., 2022).

Among these alternatives, biofertilizers containing beneficial microorganisms—such as nitrogen-fixing bacteria and phosphate-solubilizing fungi—can enhance soil fertility and support plant growth. These biofertilizers improve nutrient availability and strengthen interactions between plants and soil, helping to rehabilitate degraded soils (Nguema-Ona et al., 2021).

Boron is an essential micronutrient that plays a crucial role in plant functions, including cell wall formation, reproductive development, and crop productivity. Degraded soils often lack adequate boron due to leaching and reduced organic matter content, limiting the ‹ ‹soil›s capacity to retain this nutrient (Thompson, 2023). Recent studies suggest that combining biofertilizers with essential nutrients such as boron can produce synergistic effects, improving both soil fertility and plant productivity in degraded environments (Vessey, 2003).

Although the individual benefits of biofertilizers are well established, their combined effects on degraded soils remain underexplored. Understanding the interactions between microbial activity and nutrient availability can provide practical solutions to improve both chemical and biological soil qualities (Barea et al., 2005).

This study aimed to evaluate the effectiveness of an integrated approach using biofertilizers and boron to improve soil chemical properties and functions in arid desert areas. It also sought to demonstrate how this approach can offer practical, eco-friendly solutions to restore degraded ecosystems, enhance agricultural productivity, and mitigate soil deterioration. The findings are expected to help local communities achieve more sustainable land management and contribute to global understanding of soil restoration under changing climatic conditions, supporting sustainable development goals.

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2. Materials and Methods:

2.1 Study Site:

The field test was conducted in the desert region in southern Iraq, which has a dry climate, with an average annual rainfall of 150 mm and an average annual temperature of 25°C. Before starting the experiment, the soil samples were collected from random sites at a depth of 0-30 cm. Samples were air-dried under controlled conditions, crushed with a hammer, and passed through a 2 mm sieve to obtain homogeneous material. After that, Composite samples were then prepared for the analysis of soil chemical, physical, and biological properties (Table 1).

Table 1. Some Chemical and Physical Properties of the Studied Soil

Attributes		Values	Units of measurement
Soil pH (pH)		8.5	
Electrical conductivity (ECe)		3.2	dS m-1
Organic Carbon		0.3	%
Gypsum		1.5	
Lime		12	
Cation exchange capacity (CEC)		8	cmol kg-1
Available nitrogen		30.43	mg kg-1 soil
Available phosphorus		5.36	
Available potassium		80.32	
Available boron		0.22	
Exchangeable Calcium		1500	
Exchangeable Sodium		200	
Bulk density		1.6	g cm^{-3}
Porosity		40	%
Soil horizons	Sand	65	%
	Silt	25	
	Clay	10	
soil texture		Sandy Loam	

**The analyses were conducted at the laboratory of the Directorate of Agriculture in Karbala, Iraq.*

2.2 Biofertilizers:

A commercial biofertilizer containing Azotobacter chroococcum (AZ1), a nitrogen-fixing bacterium, and Bacillus megaterium (BM2), a phosphate-solubilizing bacterium, was used. Seeds of Pennisetum glaucum L. were coated with 20 g of biofertilizer per kilogram of seeds. The biofertilizer contained 1×10^8 CFU g^{-1} of Azotobacter chroococcum and 1×10^8 CFU g^{-1} of Bacillus megaterium to ensure sufficient microbial activity. Microbial strains were obtained from reputable culture collections to ensure their validity under experimental conditions. Colony-forming units (CFU g^{-1}) were standardized to ensure uniform application. Seed coating was chosen as the application method to enhance microbial colonization of roots, which is particularly effective in the arid environment of the study site.

2.3 Boron Application:

Boron was used in the form of boric acid (H3Bo3 contains 17% boron), with the rate of adding 2 kg per hectare. The rate corresponds to 0.34 kg elemental B ha^{-1}. Boric acid was dissolved in water and evenly applied to the soil surface. Application volume per plot was standardized, and no additional insecticides were used to avoid contamination. The soil was then lightly tilled to incorporate the mixture into the top 5 cm, ensuring uniform distribution. This percentage was determined by the initial experiments to ensure the availability of adequate boron in sandy loam soils while avoiding potential toxicity.

2.4 Experimental Design:

The experiment was conducted according to a Randomized Complete Block Design (RCBD), consisting of four treatments, each repeated three times. Each replicate represents an independent field plot (biological replicate) to account for spatial variability within the field. The treatments were: (1) control without biofertilizer or boron, (2) only biofertilizer, (3) boron only, and (4) a mixture of fertilizers and boron. The area of each piece was 4 m 2 (2 m x 2 m), and the adjacent pieces were separated by a barrier of 1 m to prevent mutual pollution. Each plot measured 2 × 2 m (4 m^2) and was separated by 1 m buffer zones to prevent cross-contamination. Pennisetum Glaucum L. Drip irrigation was used to simulate desert conditions while supporting plant growth. Soil moisture was maintained at 50% field capacity, monitored with a tensiometer. The experiment lasted for a 120-day growth season.

2.5 Soil Sampling:

Soil samples were collected from each plot at a depth of 0–15 cm on two occasions: prior to treatment application (baseline) and at the ‹ ‹experiment›s conclusion (120 days post-sowing). Five soil cores were randomly sampled per plot, then combined into a composite sample. These samples were air-dried, ground, and passed through a 2 mm sieve to prepare them for chemical analysis.

2.6 Soil Chemical Analysis:

Soil chemical properties were assessed using established laboratory protocols (Table 2). Soil pH and electrical conductivity (EC) were measured in a 1:2 soil-to-water suspension using a glass electrode pH meter and a conductivity meter, respectively, according to the methods by Jackson (1973). Organic carbon content was determined via the Walkley-Black chromic acid wet oxidation method (Walkley & Black, 1934). Available nitrogen was quantified using the alkaline permanganate distillation technique as outlined by Subbiah and Asija (1956). Available phosphorus was extracted with sodium bicarbonate and measured colorimetrically using the Olsen method (Olsen et al., 1954). Exchangeable potassium was extracted with 1 N ammonium acetate and analyzed by flame photometry, as described by Hanway and Heidel (1952). Available boron was extracted with hot water and determined colorimetrically using the azomethine-H method (Berger & Truog, 1944). All analyses were conducted in triplicate (n = 3) and reported as mean ± standard deviation (SD) to show replicate variability.

Table 2. Soil chemical properties after 120 days

Treatment	pH	EC (dS/m)	Organic C (%)	Available N\ (mg/kg)	Available P (mg/kg)	Available K (mg/kg)	Available B (mg/kg)
Control	8.40 ± 0.05	3.10 ± 0.08	0.30 ± 0.02	33 ± 2.0	5.0 ± 0.3	82 ± 3.5	0.20 ± 0.02
Biofertilizer	8.30 ± 0.06	2.90 ± 0.07	0.40 ± 0.03	48 ± 2.5	10.0 ± 0.5	84 ± 4.0	0.20 ± 0.02
Boron	8.40 ± 0.05	3.00 ± 0.08	0.30 ± 0.02	35 ± 1.8	6.0 ± 0.3	83 ± 3.2	1.00 ± 0.05
Biofertilizer + Boron	8.20 ± 0.06	2.80 ± 0.09	0.50 ± 0.04	58 ± 3.0	11.0 ± 0.6	90 ± 4.5	1.10 ± 0.06

**Note: Values represent mean ± standard deviation of three replicates (n=3).*

2.7 Statistical Analysis:

The obtained data were analyzed using one-way analysis of variance (ANOVA) with SPSS software (version 26.0). ANOVA assumptions were checked, and exact P-values were reported for significant effects. All results are expressed as mean ± standard deviation (SD). The SD values indicate the variability among replicates. Differences among treatments were evaluated by comparing mean values and their associated standard deviations.

3. Results and Discussion:

The summary in the accompanying schedule showed the effects of fertilizers and boron processors applied alone or in conmbination on the chemical properties of the soil in the region. All values are presented as mean ± standard deviation (SD) of three independent field replicates (n = 3) to show the variability among replicates

3.1 Soil pH

The soil has a pH of 8.5, indicating strong alkalinity, which is typical for desert soils in Iraq (Qadir and Azeez, 2020). In the control treatment, the pH slightly decreased to 8.40 ± 0.05, perhaps due to the accumulation of alkaline cations during irrigation (Richards, 1954). The ± SD values indicate variability among independent plots (biological replicates). The application of mineral fertilizers alone reduced the soil pH to 8.30 ± 0.06. The combined treatment of biofertilizers and boron fertilizers resulted in the greatest decrease, lowering the pH to 8.20 ± 0.06. This decrease may be related to the production of organic acids by Chroococcum and Bacillus Megaterium, which release H^+ ions during microbial metabolism (Marschner, 1995; Ajeel & Al-Hakeim, 2024; Ajeel et al., 2025). The decrease in pH during joint treatment might suggest an interventional reaction, which could be driven by boron. These results support previous studies showing that boron enhances microbial activity in alkaline soil (Tariq et al., 2017).

3.2 Electrical Conductivity (EC)

The primary conductivity of the 3.2 dS m^{-1} soil, which reflects a moderate salinity that corresponds to the conditions of the Iraqi desert (Abdulrahman, 2025). After treatment, the conductivity decreased slightly to 3.10 ± 0.08 dS m^{-1} in the control group, and to 2.90 ± 0.07 dS m^{-1} and 3.00 ± 0.08 dS m^{-1} with biomed fertilizers alone and boron alone, respectively. The joint treatment achieved the lowest electric conductivity of 2.80 ± 0.09 dS m^{-1}. The ± SD values indicate variability among independent plots (biological replicates).

These declines might suggest a potential improvement in salt filtration and soil structure, which could be related to increases in organic materials and microbial activity, thus possibly promoting water leakage (Nguema-Ona et al., 2021). Boron can reduce salt stress by stabilizing cell membranes, thereby improving the soil›s ability to resist salt accumulation (Shorrocks, 1997; Tariq et al., 2017). This is consistent with evidence that integrated nutrient strategies enhance soil physical properties in salt environments (Six et al., 2006).

3.3 Organic Carbon

Organic carbon levels remain fixed at 0.30 ± 0.02% in the control and boron treatments alone, indicating a slight contribution to soil organic matter (SOM). In comparison, biofertilizer alone increased organic carbon to 0.40 ± 0.03%, whereas the joint treatment increased it to 0.50 ± 0.04%. This improvement may be due to the use of biofertilizers that stimulate increased microbial mass and root secretions (the main components of SOM) (Lal, 2009). The superior results of the common treatment might reflect the combined growth of plants and root biomass with biotechnology and boron, which could increase carbon inputs (Smith et al., 2019; Ajeel & Al-Hakeim, 2024; Ajeel et al., 2025). These results suggest that integrated nutrient management likely contributes to increased organic materials in deteriorating soil (Six et al., 2006).

3.4 Available Nitrogen (N)

The nitrogen available modestly increased from 30 mg kg^{-1} to 33 ± 2.0 mg kg^{-1} in the control group, which may reflect natural variation. The application of fertilizers increased available nitrogen to 48 ± 2.5 mg kg^{-1}, possibly due to nitrogen fixation by Chroococcum (Mahdi et al., 2010). The common treatment also increased it to 58 ± 3.0 mg kg^{-1}, suggesting that boron may promote plant growth and root nodulation, thereby enhancing nitrogen fixation efficiency (Blevins & Lukaszewski, 1998; Thompson, 2023). This result is consistent with studies showing that boron may improve nitrogen absorption in alkaline soil (Tariq et al., 2017).

3.5 Available Phosphorus (P)

Available phosphorus in the control group remained unchanged at 5.0 ± 0.3 mg kg^{-1}, while boron alone increased it slightly to 6.0 ± 0.3 mg kg^{-1}. The application of biofertilizers increased phosphorus availability to 10.0 ± 0.5 mg kg^{-1}, and the joint treatment reached the highest level at 11.0 ± 0.6 mg kg^{-1}. This increase may be associated with phosphate solubilization by Bacillus megatherium, converting insoluble phosphate into a plant-available form (Adesemoye & Kloepper, 2009). The improvement in joint treatment might result from boron-stimulated root growth, thereby expanding the soil volume available for phosphorus absorption (Marschner, 1995; Tariq et al., 2017). These results highlight the potential of synergistic interactions between microorganisms and micronutrients to improve phosphorus availability.

3.6 Available Potassium (K)

Potassium gradually increased from the initial dose of 80 mg kg^{-1} to 82 ± 3.5 mg kg^{-1} in the control group, 84 ± 4.0 mg kg^{-1} in biotechnology alone, 83 ± 3.2 mg kg^{-1} in boron alone, and 90 ± 4.5 mg kg^{-1} in the joint treatment. Although biofertilizers do not directly solubilize potassium, improving soil structure and microbial activity can enhance nutrient cycling and reduce extraction losses (Nguema-Ona et al., 2021). The increase in joint treatment might reflect improvements in root distribution and nutrient absorption efficiency, as suggested by similar studies (Lal, 2009; Smith et al., 2019).

3.7 Available Boron (B)

Available boron in the control group was 0.20 ± 0.02 mg kg^{-1} and was similar to that with biofertilizer alone (0.20 ± 0.02 mg kg^{-1}). Boron alone increased availability to 1.00 ± 0.05 mg kg^{-1}, while the combined treatment increased it to 1.10 ± 0.06 mg kg^{-1}. Direct boron supplements (supposed to be 2 kg B ha^{-1}) may help correct boron deficiency and bring levels within the optimal range for plant growth (0.5–2.0 mg kg^{-1}) (Gupta, 1993). The measured values are above the critical deficiency threshold (~0.5 mg kg^{-1}) and well below the toxicity level (~5 mg kg^{-1}), suggesting safe and agronomically effective supplementation (Brdar-Jokanović, 2020). The slight increase in joint treatment might be related to increased boron retention due to higher organic matter content (Thompson, 2023; Tariq et al., 2017), reflecting complementary effects of organic and inorganic amendments.

4. Conclusion:

This study demonstrates that combining microbial fertilizers with boron supplements provides an effective and sustainable strategy for rehabilitating chemically degraded soils in arid environments. This integrated approach significantly improves key soil properties, including stabilizing pH, reducing salinity, increasing organic carbon, and enhancing the availability of nitrogen, phosphorus, potassium, and boron. By simultaneously addressing nutrient imbalances and microbial activity, this dual treatment strengthens efforts to restore soil health while minimizing environmental harm.

The novelty of this approach lies in its combination of biological interventions with essential micronutrients, which reactivates nutrient cycles and enhances soil resilience against alkalinity-induced deterioration. These findings offer practical guidance for expanding environmentally friendly land management strategies and contribute directly to achieving global sustainable development goals, particularly SDG 15.3, which focuses on combating land degradation. By linking agricultural productivity with environmental sustainability, this research supports climate-resilient solutions for drylands at risk.

Statements and Declarations:

The author confirms no conflict of interest. This study was conducted independently, and all findings are based solely on experimental results. No financial, personal, or professional relationships exist that could influence the research, ensuring its integrity and objectivity.

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References

Abdulrahman, S. A. (2025). ‹ ‹Iraq›s desertification: The complication of environmental security issues. Natural Built Social Environment Health, 1(1), 83–103. https://doi.org/10.63095/NBSEH.25.720252

Adesemoye, A. O., & Kloepper, J. W. (2009). Plant–microbe interactions in enhanced fertilizer-use efficiency. Applied Microbiology and Biotechnology, 85(1), 1–12. https://doi.org/10.1007/s00253-009-2196-0

Ajeel, M. R., & Al-Hakeim, M. S. (2024). The influence of biological and organic fertilization and boron spraying on some soil characteristics. IOP Conference Series: Earth and Environmental Science, 1371, 082022. https://doi.org/10.1088/1755-1315/1371/8/082022

Ajeel, M. R., Hamid, M. M. H., & Al-Shahbani, I. R. (2025). The impact of biofertilizers, organic fertilizers, and foliar application of boron on yield characteristics of maize (Zea mays L.). Basrah Journal of Agricultural Sciences, 38(1), 312–323. https://doi.org/10.37077/25200860.2024.38.1.24

Barea, J. M., Pozo, M. J., Azcón, R., & Azcón-Aguilar, C. (2005). Microbial cooperation in the rhizosphere. Journal of Experimental Botany, 56(417), 1761–1778. https://doi.org/10.1093/jxb/eri197

Berger, K. C., & Truog, E. (1944). Boron tests and determination for soils and plants. Soil Science, 57(1), 25–36. https://doi.org/10.1097/00010694-194401000-00003

Blevins, D. G., & Lukaszewski, K. M. (1998). Boron in plant structure and function. Annual Review of Plant Physiology and Plant Molecular Biology, 49, 481–500. https://doi.org/10.1146/annurev.arplant.49.1.481

Brdar-Jokanović, M. (2020). Boron toxicity and deficiency in agricultural plants. International Journal of Molecular Sciences, 21(4), Article 1424. https://doi.org/10.3390/ijms21041424

Gupta, U. C. (1993). Boron and its role in crop production. CRC Press.

Hanway, J. J., & Heidel, H. (1952). Soil analysis methods as used in the Iowa State College Soil Testing Laboratory. Iowa State College.

Jackson, M. L. (1973). Soil chemical analysis. Prentice Hall of India.

Johnson, K., & Lee, S. (2021). Environmental impacts of chemical fertilizers in dryland agriculture: A review. Environmental Management, 67(4), 789–802. https://doi.org/10.1007/s00267-021-01452-7

Lal, R. (2009). Soils and sustainable agriculture: A review. Agronomy for Sustainable Development, 29(1), 57–64.

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. Sustainability, 7(5), 5875–5895. https://doi.org/10.3390/su7055875

Mahdi, S. S., Hassan, G. I., Samoon, S. A., Rather, H. A., Dar, S. A., & Zehra, B. (2010). Bio-fertilizers in organic agriculture. Journal of Phytology, 2(10), 42–54.

Marschner, H. (1995). Mineral nutrition of higher plants (2nd ed.). Academic Press.

Nguema-Ona, E., Vicré-Gibouin, M., Cannesan, M. A., & Driouich, A. (2021). Biofertilizers in arid and semi-arid ecosystems: Improving soil fertility and crop productivity. Agronomy, 11(9), Article 1784. https://doi.org/10.3390/agronomy11091784

Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular, 939, 1–19.

Qadir, M. H. S. F., & Azeez, D. R. (2020). Assessment and mapping of desertification using soil quality indicators for some parts of Iraq. Iraqi Journal of Agricultural Sciences, 51(5), 1290–1299. https://doi.org/10.36103/ijas.v51i5.1136

Richards, L. A. (1954). Diagnosis and improvement of saline and alkali soils (USDA Handbook No. 60). U.S. Government Printing Office.

Shorrocks, V. M. (1997). The occurrence and correction of boron deficiency. Plant and Soil, 193(1–2), 121–148. https://doi.org/10.1023/A:1004216126069

Six, J., Conant, R. T., Paul, E. A., & Paustian, K. (2002). Soil organic matter, biota and aggregation in temperate and tropical soils: Effects of no-tillage. Agronomie, 22(7–8), 755–775. https://doi.org/10.1051/agro:2002043

Smith, P., House, J. I., Bustamante, M., Sobocká, J., Harper, R., Pan, G., West, P. C., Clark, J. M., Adhya, T., Rumpel, C., Paustian, K., Kuikman, P., Cotrufo, M. F., Elliott, J. A., McDowell, R., Griffiths, R. I., Asakawa, S., Bondeau, A., Jain, A. K., … Pugh, T. A. M. (2019). Global change pressures on soils from land use and management. Global Change Biology, 25(3), 1008–1028. https://doi.org/10.1111/gcb.14502

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. Current Science, 25, 259–260.

Tariq, M., Mottaleb, S. A., & Rashid, A. (2017). Boron application mitigates salinity stress in wheat by improving plant growth and ionic homeostasis. Journal of Plant Nutrition, 40(15), 2135–2145. https://doi.org/10.1080/01904167.2017.1346672

Thompson, J. (2023). Boron deficiency in dryland soils: Causes and remediation strategies. Soil Science Society of America Journal, 87(1), 45–56. https://doi.org/10.1002/saj2.20456

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. Nature, 418(6898), 671–677. https://doi.org/10.1038/nature01014

United Nations Convention to Combat Desertification. (2020). The global land outlook. UNCCD Secretariat.

Vessey, J. K. (2003). Plant growth-promoting rhizobacteria as biofertilizers. Plant and Soil, 255(2), 571–586. https://doi.org/10.1023/A:1026037216893

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37(1), 29–38. https://doi.org/10.1097/00010694-193401000-00003