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Sustainable Agriculture through Soil Amendments and Foliar Nutrition: Mini review of the Benefits of Biochar, Zeolite, Compost and Micronutrients in Mitigating Deficit Irrigation Water

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ABSTRACT

Egypt's arid climate and limited water resources present significant challenges hindering the achievement of sustainable agriculture. To address these challenges, innovative strategies are required to optimize water use and enhance crop productivity. Effective management of these constraints is essential for developing agricultural practices that can sustain food production and meet the demands of a growing population. This review examines the effects of soil amendments such as biochar, zeolite, and compost, as well as foliar nutrition involving boron, copper, and selenium, on plant growth and yield quality under deficit irrigation conditions. Deficit irrigation is a water conservation strategy that aims to minimize crop yield reduction while conserving water, thus necessitating improved soil and plant management techniques. Recent research highlights how these soil amendments and nutritional interventions can significantly improve water retention, increase nutrient availability, and enhance plant stress resilience. By focusing on amendments like biochar, zeolite and compost, alongside foliar treatments of essential micronutrients, this article underscores their potential to enhance water use efficiency and boost crop resistance to environmental stresses. These strategies are vital for advancing sustainable agricultural practices, particularly in regions grappling with water scarcity and climatic challenges. The current study emphasizes the importance of these approaches in supporting resilient and productive farming systems, ultimately contributing to more sustainable agricultural practices in water-limited environments.

Keywords:: Biochar, Zeolite, Compost, Nutrients

INTRODUCTION

Background

Egypt's agricultural sector is heavily dependent on the Nile River, which supplies more than 95% of the country's freshwater. However, increasing demands from a growing population, climate change impacts and upstream water use have exacerbated water scarcity issues (Ghazi *et al.* 2023).

The country is classified as one of the most water-stressed nations globally, with per capita water availability falling below the critical threshold of 1,000 m3 per year (Soliman *et al.* 2024).

The Need for Deficit Irrigation

To address water scarcity, Egypt has increasingly adopted deficit irrigation practices, which involve applying water below crop evapotranspiration needs. While this method conserves water, it can lead to stress on plants, necessitating improved agricultural management practices to sustain crop yields and quality (Abd El-Aty *et al.* 2024; Mostafa *et al.* 2024).

Objectives

This review examines the role of soil amendments (biochar, zeolite, and compost) and foliar nutrition (boron, copper, and selenium) in mitigating the adverse effects of deficit irrigation. The current study aim to elucidate the mechanisms by which these interventions enhance water retention, nutrient uptake, and overall plant resilience, contributing to improved growth and yield quality.

Soil Amendments under Deficit Irrigation

Biochar

Biochar, a carbon-rich product derived from biomass pyrolysis, improves soil properties by enhancing water retention, increasing nutrient availability, and promoting beneficial microbial activity. Biochar's porous structure (Fig1) significantly enhances soil water holding capacity, critical under deficit irrigation.

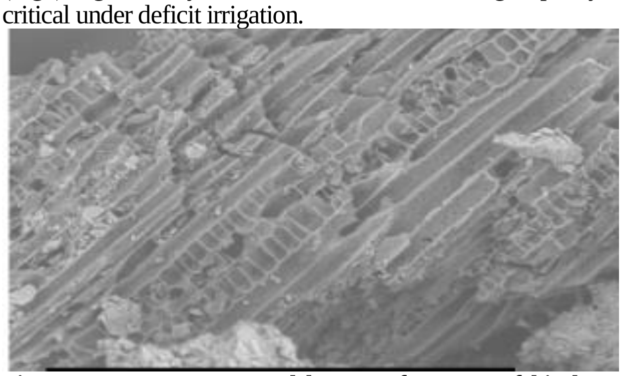

Fig. 1. Porous structure and large surface area of biochar (citation from Juriga and Šimanský, 2018)Luo *et al.* (2020) investigated how biochar application rates of 0.0, 4.0, 8.0, and 16 g/kg influenced soil bulk density and nutrient retention. They examined long-term changes in soil organic-C, total-N, total-P, ammonium-N, and nitrate-N concentrations eight years after biochar application. The findings revealed a significant increase in soil organic-C and nitrate-N levels in the 0–40 cm soil depth across all tested conditions. Notably, nitrate-N levels in Lou and Dark Loessial soils decreased with a 4 g/kg biochar application but increased significantly under 8 g/kg and 16 g/kg rates. In contrast, nitrate-N levels in Loessal soil remained relatively stable regardless of biochar application rate.

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It adsorbs nutrients, reducing leaching losses and ensuring a steady supply to plants. Biochar supports soil microbial communities that facilitate nutrient cycling and plant growth (Mosa *et al.* 2020; Juriga and Šimanský, 2018).

Abdelrasheed *et al.* (2021) examined the potential impacts of biochar on onion growth, productivity and nutritional quality under conditions of deficit irrigation. Their study revealed that deficit irrigation had a detrimental effect on onion resilience to drought stress. However, these negative impacts were mitigated following the application of biochar to the soil. Specifically, biochar enhanced onion growth, increased the levels of photosynthetic pigments, improved water relations and enhanced yield characteristics in onion plants subjected to deficit irrigation. Furthermore, biochar supplementation improved biochemical responses, boosted the activity of antioxidant enzymes, and enriched the nutrient content of onion plants experiencing deficient irrigation conditions.

Aneseyee and Wolde, (2021) examined the impact of two biochar types, one from grass and the other from chat waste (Catha edulis), on soil properties as well as the growth and yield of onion plants. Their findings indicated that grass biochar positively influenced soil properties, enhancing soil fertility more effectively than chat biochar, which had a lesser impact. The application of grass biochar significantly increased the marketable yield of onion bulbs, while the yield of unmarketable bulbs decreased. I Overall, their study concluded that biochar applications, particularly grass biochar, can improve soil fertility and contribute to environmental sustainability.

Ghazi and El-Sherpiny (2021) explored the impact of biochar on water conservation during irrigation and its influence on maize plant growth and yield. Their study revealed that extending the irrigation interval to 10 and 12 days led to a noticeable decline in plant performance compared to the standard 8-day irrigation schedule. Nevertheless, the addition of biochar enhanced plant growth, resulting in higher maize yield and improved quality compared to plants that did not receive biochar treatment.

Calcan *et al.* (2022) examined the influence of biochar on various soil physicochemical properties and the growth of tomato plants across different soil types. Their study demonstrated that biochar significantly enhanced tomato plant growth. This improvement was attributed to alterations in soil properties induced by biochar. The addition of biochar resulted in higher electrical conductivity, increased pH levels, and elevated concentrations of both soluble and available nutrients. Additionally, biochar application led to a substantial reduction in soil bulk density, approximately by 50%, which facilitated better root development and, consequently, improved the plant's ability to absorb water and nutrients.

Sun *et al.* (2022) examined how biochar influences various soil chemical properties, including pH, EC, CEC, soil organic carbon (SOC), and total carbon (TC). Their findings indicated that biochar had the most significant impact on SOC, with an effect size of 0.50, followed by the soil pH at 0.39, TC at 0.35, EC at 0.21, and CEC at 0.20. Generally, biochar increased these values compared to the corresponding soil without biochar.

Higashikawa *et al.* (2023) investigated the effects of applying progressively higher rates of biochar over two consecutive cropping seasons. Their findings indicated that the maximum onion yield of 39.9 Mg ha^{-1} was achieved with a biochar application rate of 5.9 Mg ha^{-1} in the first season. In the following year, each additional Mg ha^{-1} of biochar contributed to a 308 kg ha^{-1} increase in onion yield. Additionally, the study demonstrated that combining biochar with mineral fertilizers not only boosted onion yield but also enhanced overall soil fertility.

El-Ghamry *et al.* (2024) improved onion growth and yield quality under water deficit conditions by incorporating biochar as a soil amendment. Their research showed that traditional irrigation methods resulted in the highest yields in terms of both quantity and quality. However, plant performance diminished under reduced water treatments. Significantly, the addition of biochar led to substantial enhancements in both the qualitative and quantitative aspects of onion yield compared to the control group.

Cedeño *et al.* (2024) investigated the impact of three types of biochar (derived from peanut shells, rice husks, and cocoa husks) and their varying application rates (1, 1.5, 3 and 5%) on onion plants, along with a control group with no biochar. Each type of biochar had a distinct nutrient composition, with cocoa husk biochar (CHB) being the richest in essential elements. The study found no significant difference in overall plant growth metrics such as height, leaf number, and root length across biochar types compared to the control. However, certain plant parts showed varied responses. The tallest onion plants were observed with the application of 5% cocoa husk biochar and 1% peanut husk biochar, reaching 71 cm and 65 cm respectively. The longest roots, at 9 cm, were produced with 3% and 5% peanut husk biochar, whereas the shortest roots were seen with 1.5% rice husk biochar.

Zeolite

Zeolites are aluminosilicate minerals known for their high cation exchange capacity and water retention properties (Fig 2). Zeolites improve soil nutrient retention by trapping and slowly releasing essential cations like potassium and ammonium. They enhance soil aeration and porosity, which is beneficial for root growth under water-limited conditions (Kurniawan *et al.* 2019; Mondal *et al.* 2021).

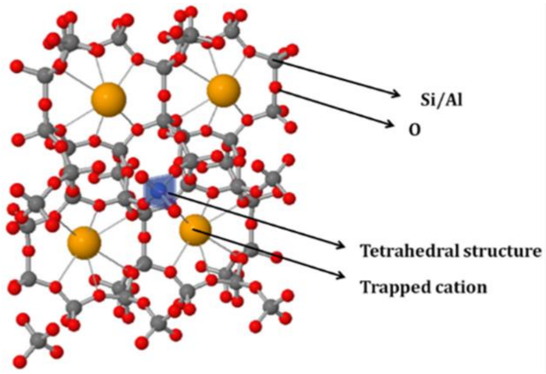

Fig. 2. Zeolite structure (citation from Mondal *et al.* 2021)

Ippolito *et al.* (2019) examined the effects of different methods of incorporating zeolite into the soil on moisture retention. Their results revealed that thoroughly integrating zeolite into the soil significantly enhanced the soil's water retention capacity and overall moisture levels. Similarly, Rosalina *et al.* (2019) demonstrated that the addition of zeolite to soil led to an increase in total nitrogen content and improved cation exchange capacity.

Seddik *et al.* (2019) assessed the impact of applying natural zeolite at a rate of 2.0 tons per feddan on various soil properties. Their findings indicated that zeolite application markedly improved soil moisture parameters, such as field capacity, available water, and wilting point. Additionally, zeolite increased total soil porosity and boosted the availability of essential nutrients like nitrogen (N), phosphorus (P), and potassium (K).

Wu *et al.* (2019) investigated the impact of incorporating zeolite into soil under an alternating wet-dry irrigation system, with a focus on soil water retention, water usage efficiency, and nutrient levels. Their study revealed that the addition of zeolite significantly enhanced field capacity and decreased the number of unproductive tillers. As a result, water savings were achieved, with a reduction of 5.8% during the tillering stage and 12% during the milky ripening stage of the crop.

Bahador and Tadayon, (2020) explored how hemp responds physiologically and biochemically to drought stress and the application of zeolite clinoptilolite. They conducted their study with four levels of irrigation stress, severe (40% of the crop's water requirement), moderate (60%), mild (80%), and well-watered (100%), and tested three zeolite application rates (0, 5, and 10 tons per hectare). The research demonstrated that drought stress adversely affected hemp’s morphological traits, chlorophyll levels, dry matter, and oil yield, while enhancing carotenoid content, antioxidant enzyme activity, and oil content. Applying zeolite reduced the negative impacts on dry matter and oil yield, with the most effective results seen at 10 tons per hectare under mild stress. Furthermore, zeolite helped maintain antioxidant enzyme activity closer to optimal levels, particularly under mild stress conditions.

Khaghani *et al.* (2020) investigated the impact of zeolite application (0.0, 2.0,4.0 and 6.0 ton ha^{-1}) on garlic plant performance under varying water stress conditions (100, 75, 50 and 25% of irrigation requarment). Their findings indicated that garlic plant performance declined with reduced irrigation water levels. However, applying zeolite at different rates enhanced plant performance significantly under water deficit treatments.

El-Mahdy *et al.* (2022) examined the effects of three irrigation intervals (every 7, 9, and 11 days) and the addition of zeolite on the performance and productivity of soybean plants. The results demonstrated that incorporating zeolite into the soil improved all measured growth and productivity parameters under water deficit conditions, in comparison to soybean plants grown in unamended soil. Additionally, zeolite significantly enhanced soil fertility attributes and improved the soil's water holding capacity.

Doklega *et al.* (2024) investigated the effectiveness of zeolite as a soil amendment for conserving irrigation water and boosting common bean plant performance. Their study found that the application of zeolite decreased the accumulation of peroxidase (POX) and catalase (CAT) under water deficit conditions. Similarly, El-Ghamry *et al.* (2024) improved onion growth and yield quality under deficit irrigation by incorporating zeolite as a soil amendment. Their research revealed that traditional irrigation methods yielded the best results in terms of both quantity and quality. Despite reduced performance under water deficit conditions, zeolite application notably enhanced both the qualitative and quantitative aspects of onion yield compared to the control treatment.

Compost

Compost is a valuable organic amendment that provides nutrients, enhances soil structure, and supports microbial diversity. Rich in organic matter, compost releases nutrients gradually, ensuring a sustained supply for crops. It improves soil texture and water infiltration, mitigating the impacts of reduced irrigation. Compost boosts microbial populations that decompose organic matter and enhance nutrient availability (Heyman *et al.* 2019).

Khosravi Shakib *et al.* (2019) investigated how different irrigation regimes and potting media affect the morpho-physiological and biochemical traits of pot marigold. They used three irrigation levels—80%, 60%, and 40% of available water content—and tested five potting media treatments: 20% and 30% vermicompost, 20% and 30% manure compost, and a control mix. The study found that water deficit reduced morpho-physiological parameters, chlorophyll, and carotenoid levels. However, the use of vermicompost and manure compost helped alleviate these adverse effects. Water deficit also increased lipid peroxidation, and activities of catalase and peroxidase, but these were lowered by adding vermicompost and manure compost. Plants grown in substrates with 30% vermicompost or 30% manure compost had about three times higher total dry mass and water use efficiency compared to those grown in the control sand-soil mix.

Ghazi and El-Sherpiny (2021) assessed how compost affects water conservation and the performance of maize plants under different irrigation schedules. They discovered that less frequent irrigation (every 10 and 12 days) led to a notable decline in plant performance compared to more frequent irrigation (every 8 days). Nevertheless, incorporating compost improved plant performance and enhanced both the yield and quality of maize compared to crops grown without compost.

Turfan (2021) investigated the effects of various organic fertilizer mixtures on garlic plants under conditions of 50% water deficiency. The study found that garlic bulbs treated with organic fertilizers had superior attributes, including greater bulb weight, length, diameter, lycopene, flavonoids, total phenolic content, and free amino acids, compared to those from the control group.

Tahiri *et al.* (2022) examined how compost influences tomato growth, yield, and drought tolerance under two irrigation conditions: (1) well-watered plants maintained at 75% field capacity and (2) water-stressed plants at 35% field capacity. The study found that water stress negatively impacted plant growth traits, yield, and the balance of antioxidant enzymes. However, compost application effectively alleviated these adverse effects and improved drought tolerance.

Rahimi *et al.* (2023) examined the effects of various organic fertilizers (vermicompost, manure compost, and animal manure) on thyme plant performance under different water stress conditions. They utilized three irrigation regimes: I1 (irrigation after 60 mm evaporation from an A pan), I2 (irrigation after 90 mm), and I3 (irrigation after 120 mm). The study found that delayed irrigation reduced chlorophyll and carotenoid levels. However, mild water stress conditions resulted in increased oil content and yield, with peak values of 2.61% and 3.68 g/m², respectively. The application of vermicompost further enhanced these properties. While water deficit decreased nutrient uptake (NPK), relative water content, biological yield, and seed yield, the use of organic fertilizers improved these factors across all irrigation regimes

El-Ghamry *et al.* (2024) enhanced the growth performance and yield quality of onions under deficit irrigation conditions by using compost as a soil amendment. Their findings indicated that traditional irrigation methods produced the highest quantitative and qualitative yields. However, performance declined under water deficit treatments. Notably, the application of compost led to significant improvements in both qualitative and quantitative traits of onions compared to the control treatment.

Foliar Nutrition under Deficit Irrigation

Boron

Boron is crucial for cell wall formation and reproductive development in plants. Boron strengthens cell walls, enhancing plant structural integrity and resistance to water stress. Adequate boron is essential for pollen viability and seed development, critical under stress conditions. Application of boron to plants not only enhances resistance to drought stress but also B plays a critical role in regulating water content within the plants, thus maintaining higher relative water content under drought conditions (Sarafi *et al.* 2018).

Abdel-Motagally *et al.* (2018) explored how foliar application of boron affects wheat yield under water stress conditions. Their study revealed that boron application significantly enhanced all growth and yield parameters compared to untreated plants, even under reduced water availability (50% of the crop's water requirements). The reduction in stress indicators, such as proline and hydrogen peroxide (H_2O_2), coupled with increased pigment content, indicates that boron foliar treatment helps mitigate the adverse effects of water stress on wheat plants.

Naeem *et al.* (2018) assessed the effectiveness of foliar boron application at concentrations of 0.0, 2.0, 4.0, and 6.0 mg L^{-1} in mitigating drought-induced physiological disorders in maize plants. Drought stress led to reduced water status, compromised photosynthetic capacity, impaired membrane integrity, redox potential imbalance, and decreased tissue boron levels. The application of boron significantly improved maize growth by enhancing water status, photosynthetic performance, tissue boron concentration, and boosting the antioxidative defense system. Additionally, boron treatment reduced the accumulation of total free amino acids, proline, malondialdehyde (MDA), and total soluble sugars, thereby ameliorating the effects of water deficit.

Aghdasi *et al.* (2021) investigated the effects of boron foliar spray on camelina plants subjected to different drought conditions. They applied three irrigation regimes: full irrigation (FI) at 50% available soil water (ASW), withholding irrigation at 20% ASW from full flowering to silicle formation (WI1), and withholding irrigation at 20% ASW from silicle formation to harvest (WI2). They also tested various levels of boron foliar spray: control (no spray), distilled water, and boron concentrations of 0.5% and 1%. The study found that water deficits during the flowering and silicle formation stages resulted in decreases in seed yield by 6.7–8.4% and oil yield by 10–12%. Drought stress also deteriorated oil quality, increasing erucic acid by 3.3–5.3% and decreasing unsaturated fatty acids. Specifically, oleic acid decreased by 4.6–8.5%, linoleic acid by 3.5%, linolenic acid by 2.5%, and monounsaturated fatty acids by 1.2–2.8% compared to the control. Nonetheless, boron foliar application improved oil content by 2% to 4% under water deficit conditions.

Yadollahi-Farsani *et al.* (2021) investigated how foliar application of boron (B) affects the morpho-physiological responses, quality, and root yields of sugar beet under varying drought stress conditions. The study utilized three irrigation levels [applied after 70 mm (I1), 100 mm (I2), and 130 mm (I3) of evaporation] and compared treatments with and without boron foliar spray. The findings showed that boron application significantly improved the morpho-physiological, quantitative, and qualitative characteristics of sugar beet. It also alleviated the adverse effects of drought stress, likely due to boron's important role in osmotic adjustment and various physiological and biochemical processes in plants.

Abdallah *et al.* (2022) studied the impact of different irrigation levels and boron foliar application on the coriander plants. The study examined four drip irrigation levels (60%, 80%, 100%, and 120% of crop evapotranspiration ETc)and four boron application rates: 0, 50, 100, and 150 ppm. The findings revealed that the highest growth and fruit yield were achieved with the maximum irrigation level (120% ETc), although results were similar to those at 100% ETc. The lowest growth and yield parameters were recorded at the 60% ETc level without boron application. Essential oil yield improved under moderate water stress (80% ETc) when boron was applied at 150 ppm, which also enhanced fruit quality. The highest crop coefficient (Kc) for coriander was noted in April, with a mean value of 0.64 at the experimental site.

Akhtar *et al.* (2022) assessed the effects of boron foliar application on durum wheat grown under drought and well-watered conditions. Their findings demonstrated that boron application significantly boosted the production of key antioxidants, including catalase, superoxide dismutase, and peroxidase. These antioxidants are essential for countering oxidative stress and reducing free radical damage. The study also showed that durum wheat treated with boron yielded more grains per spike and had a higher 1000-grain weight compared to untreated plants under drought conditions. This suggests that boron application enhances the antioxidant defense system, mitigating the detrimental effects of drought and improving overall yield.

Ödemiş and Uncu, (2022) explored the effects of varying boron doses (0, 150, 225, and 300 ppm) on the yield and yield components of apricot trees under different irrigation levels: 100%, 75%, 50%, and 25% of available water holding capacity. Their study showed that the application of boron improved both fruit weight and total yield, even under conditions of water deficit.

Moitazedi *et al.* (2023) examined the impact of boron foliar application on wheat under both rainfed and supplementary irrigation conditions. They found that boron foliar spray significantly increased wheat's resilience to drought stress.

Copper

Copper plays a key role in photosynthesis and lignin synthesis, which are vital for plant growth and stress resistance. Copper is a component of plastocyanin, facilitating electron transport in photosynthesis. It supports lignin synthesis, strengthening plant tissues and improving drought tolerance (Tombuloglu *et al.* 2020).

Trong *et al.* (2019) explored the role of copper as a micronutrient in enhancing drought tolerance in common bean plants. The study revealed a positive relationship between copper application and improved drought resistance. Key parameters, including leaf water content, leaf water retention capacity, leaf transpiration rate, and root weight, were significantly improved with copper treatment, indicating its vital role in maintaining plant hydration and promoting healthy root development under drought conditions.

Fouad *et al.* (2020) examined the effect of foliar copper (Cu) application on rainfed wheat. They found that the increase in grain yield from Cu application was not directly related to the native soil Cu levels. During a rainfall season with 429 mm of precipitation, applying Cu at 0.018% concentration led to an approximately 8% increase in grain yield compared to the control. However, concentrations exceeding 0.03% caused leaf damage, highlighting the need for careful management of Cu application levels.

Jańczak-Pieniążek *et al.* (2022) examined the impact of applying an exogenous quercetin–copper complex at concentrations of 0.01%, 0.05 and 0.1% on wheat seedlings experiencing drought conditions. The study found that drought stress negatively affected the photosynthetic processes of the plants. However, foliar spraying with the quercetin derivative significantly improved various physiological parameters in drought-stressed wheat compared to the untreated control. The treatment resulted in enhanced chlorophyll fluorescence, better gas exchange rates, and increased total antioxidant capacity, suggesting that the quercetin–copper complex can mitigate the adverse effects of drought on wheat by improving photosynthetic efficiency and enhancing the plant's antioxidant defenses.

Ramadan, (2023) explored the use of copper chlorophyllin (Cu-Chl) to alleviate the adverse effects of water deficit on spinach plants. The study applied Cu-Chl at concentrations of 0%, 1%, and 2% under three irrigation levels: 100%, 75%, and 50% of crop evapotranspiration (ETc). The findings indicated that deficit irrigation at 50% ETc significantly decreased growth parameters, such as plant height, leaf number, leaf area, fresh and dry weights, and overall yield. Water stress also negatively impacted relative water content, leaf membrane stability index, electrolyte leakage, and levels of chlorophyll a, chlorophyll b, carotenoids, iron (Fe), and copper (Cu). However, Cu-Chl application notably improved these parameters, demonstrating its effectiveness in mitigating the negative effects of water deficit and enhancing plant growth and physiological health under reduced water conditions.

Selenium

Selenium, although not essential, can enhance plant growth and stress tolerance through its antioxidant properties. Selenium boosts antioxidant enzymes, mitigating oxidative stress induced by water deficit. Low concentrations of selenium have been shown to stimulate growth and yield in various crops (Lanza *et al.* 2021).

Nawaz *et al.* (2015) investigated the impact of selenium (Se) foliar application on wheat plants experiencing drought stress. The study revealed that the foliar application of Se significantly reduced osmotic potential by 13%, which in turn considerably enhanced turgor pressure by 63%. This improvement in turgor facilitated a 60% increase in the transpiration rate. Additionally, Se application promoted the accumulation of total soluble sugars by 33% and free amino acids by 118%, while also boosting the activity of the plant's antioxidant system. These physiological and biochemical enhancements collectively led to a substantial 24% increase in grain yield. Moreover, the supplemental Se application resulted in a significant increase in Se content within the plants, reaching 5.77 µg g^{-1} dry weight. It also improved the uptake of iron (Fe) by 91% and sodium by 16%, while notably reducing zinc accumulation by 54%. Importantly, the Se treatment did not affect the calcium content in the wheat plants.

Aissa *et al.* (2018) conducted a pot experiment over two months with sorghum plants to assess the protective effects of a low selenium dose (20 mg Se/L) against drought stress. The experiment included both selenium-treated and untreated plants under three water availability conditions: a control at 100% field capacity (FC), a low drought condition at 70% FC, and a high drought condition at 35% FC. The study found that selenium treatment notably enhanced plant growth, increased relative water content (RWC), and improved chlorophyll levels in the sorghum plants. These findings suggest that selenium helps mitigate the impacts of drought stress by promoting growth and improving water regulation in sorghum.

Hachmann *et al.* (2019) conducted a study to evaluate the effects of varying irrigation levels and selenium (Se) application on cauliflower growth and yield. The experimental setup included three irrigation treatments, specifically 100%, 75%, and 50% of the crop evapotranspiration rate (ETc). Selenium was either applied through foliar spray or not applied at all. The findings revealed that the application of selenium significantly enhanced the yield of cauliflower, even under conditions of reduced irrigation. Notably, the foliar application of selenium under drought stress conditions led to an increase in the total polyphenol content in cauliflower plants, indicating an improvement in the plant's stress tolerance and antioxidant capacity.

Thuc *et al.* (2021) conducted a study to investigate the impact of foliar selenium application on the drought tolerance of sesame plants. The researchers tested five different concentrations of selenium: 0, 5, 10, 20, and 40 mg/L. Their findings demonstrated that the application of selenium at lower concentrations, specifically 5 and 10 mg/L, was effective in maintaining the number of leaves and enhancing the number of capsules produced by the sesame plants under drought conditions. However, when selenium was applied at higher concentrations, particularly 20 and 40 mg/L, it led to the induction of necrosis, negatively affecting the plant health and growth.

Ghouri *et al.* (2022) investigated the role of selenium (Se) in mitigating the adverse effects of water deficiency on rice plants. The study found that the application of selenium significantly enhanced plant growth and development, improved yield, and bolstered quality traits under drought stress conditions. Selenium's application was particularly effective in promoting resilience in rice plants, allowing them to better withstand water scarcity.

Synergistic Effects and Integration

Zahedi and Moghadam (2011) investigated how drought stress affects antioxidant enzyme activities in canola with the application of zeolite and selenium. The study used two irrigation regimes: full irrigation and cessation of irrigation at the stem elongation stage. Zeolite was applied at two rates (0.0 and 10.0 t/ha), and selenium was applied via foliar spray at three concentrations of sodium selenate (0, 15, and 30 g/L). The results revealed that soil application of zeolite significantly reduced enzyme activities. In contrast, foliar application of selenium significantly increased these enzyme activities. The combined use of zeolite and selenium improved the plant's resistance to drought stress by enhancing water availability and mitigating the adverse effects of water scarcity.

Bybordi (2016) examined the impact of soil-applied zeolite and foliar selenium on rapeseed plants subjected to salinity stress. Zeolite was applied at rates of 0, 5, and 10 t/ha, while selenium was applied via foliar spray at concentrations of 0, 2, and 4 g/L. The results demonstrated a beneficial synergistic effect of combining zeolite and selenium, enhancing growth parameters and yield of rapeseed plants. In a subsequent study, Bybordi *et al.* (2018) investigated the effects of zeolite applied at three rates (0, 4, and 8 t/ha) and selenium at three rates (0, 0.5, and 1 kg/ha) on onion plants. The study found that increasing the levels of zeolite and selenium reduced the number of small-sized bulbs. Additionally, both treatments significantly improved the dry matter content, soluble solids, nitrogen content, nitrate concentration, and protein content of onions. The highest yield and enhancement of various qualitative and physiological traits, such as soluble solids, potassium, protein, chlorophyll, and photosynthesis, were achieved with the combination of 8 t/ha of zeolite and 1 kg/ha of selenium.

El-Ghamry *et al.* (2024) enhanced onion growth performance and yield quality under deficit irrigation by using biochar, zeolite, and compost as soil amendments, along with foliar applications of beneficial elements like boron, copper and selenium. They found that there were synergistic effects among the soil amendments and the beneficial elements. Growth performance, as well as both quantitative and qualitative yields, improved when a combined approach of compost and selenium foliar application was employed under water deficit conditions, compared to traditional cultivation methods that did not utilize any of the studied substances.

CONCLUSION

Integrating soil amendments like biochar, zeolite, and compost, alongside targeted foliar nutrition with boron, copper, and selenium, provides a robust strategy to enhance plant growth and yield quality under deficit irrigation. These interventions improve soil properties, enhance nutrient uptake, and bolster plant stress tolerance, contributing to sustainable and resilient agricultural practices.

REFERENCES

Abd El-Aty, A., Mohamed, S., Gad, K. M., Hefny, Y. A., & Shehata, M. O. (2024). Performance of some wheat (*Triticum aestivum* L.) genotypes and their drought tolerance indices under normal and water stress. Egyptian Journal of Soil Science, 64(1).

Abdallah, M., El-Khalek, A., Sarah, N., & AbuEl-leil, E. F. (2022). Alleviation of water stress in coriander plants by foliar application of boron. Scientific Journal of Flowers and Ornamental Plants, 9(4), 307-317.

Abdel-Motagally, F. M. F., & El-Zohri, M. (2018). Improvement of wheat yield grown under drought stress by boron foliar application at different growth stages. Journal of the Saudi Society of Agricultural Sciences, 17(2), 178-185.

Abdelrasheed, K. G., Mazrou, Y., Omara, A. E. D., Osman, H. S., Nehela, Y., Hafez, E. M., ... & Gowayed, S. M. (2021). Soil amendment using biochar and application of K-humate enhance the growth, productivity, and nutritional value of onion (*Allium cepa* L.) under deficit irrigation conditions. Plants, 10(12), 2598.

Aghdasi, S., AghaAlikhani, M., Modarres-Sanavy, S. A. M., & Kahrizi, D. (2021). Exogenously used boron and 24-epibrassinolide improved oil quality and mitigate late-season water deficit stress in camelina. Industrial Crops and Products, 171, 113885.

Aissa, N., Malagoli, M., & Radhouane, L. (2018). An approach to alleviate the impact of drought stress with selenium amendment. Iranian Journal of Science and Technology, Transactions A: Science, 42, 283-288.

Akhtar, N., Ilyas, N., Arshad, M., Meraj, T. A., Hefft, D. I., Jan, B. L., & Ahmad, P. (2022). The impact of calcium, potassium, and boron application on the growth and yield characteristics of durum wheat under drought conditions. Agronomy, 12(8), 1917.

Aneseyee, A. B., & Wolde, T. (2021). Effect of biochar and inorganic fertilizer on the soil properties and growth and yield of onion (*Allium cepa*) in tropical Ethiopia. The Scientific World Journal, 2021(1), 5582697.

Bahador, M., & Tadayon, M. R. (2020). Investigating of zeolite role in modifying the effect of drought stress in hemp: Antioxidant enzymes and oil content. Industrial crops and products, 144, 112042.

Bybordi, A. (2016). Effect of zeolite, selenium and silicon on yield, yield components and some physiological traits of canola under salt stress conditions.

Bybordi, A., Saadat, S., & Zargaripour, P. (2018). The effect of zeolite, selenium and silicon on qualitative and quantitative traits of onion grown under salinity conditions. Archives of Agronomy and Soil Science, 64(4), 520-530.

Calcan, S. I., Pârvulescu, O. C., Ion, V. A., Răducanu, C. E., Bădulescu, L., Madjar, R., ... & Jerca, I. O. (2022). Effects of biochar on soil properties and tomato growth. Agronomy, 12(8), 1824.

Cedeño, Á., Saldarriaga, V., Cedeño, G., López, G., & Mendoza, J. (2024). Effects of Biochar Type on the Growth and Harvest Index of Onion (*Allium cepa* L.). Agri., Engineering, 6(2), 1568-1580.

Doklega, S. M., Saudy, H. S., El-Sherpiny, M. A., El-Yazied, A. A., Abd El-Gawad, H. G., Ibrahim, M. F., ... & Metwally, A. A. (2024). Rhizospheric addition of hydrogel polymer and zeolite plus glutathione mitigate the hazard effects of water deficiency on common bean plants through enhancing the defensive antioxidants. Journal of Crop Health, 76(1), 235-249.

El-Ghamry, A., Ghazi, D. A., Elsherpiny, M. A., Kassem, M. A., Kassem, A.A., & Helmy, A. A. (2024). Enhancing onion growth and yield quality via soil amendments and foliar nutrition under deficit irrigation. Egyptian Journal of Soil Science, 64(2), 523-542.

El-Mahdy, S. M., El-Sherpiny, M. A., & Helmy, A. A. (2022). Suppression of irrigation water deficit stress affecting soybean production. Journal of Global Agriculture and Ecology, 25-37.

Fouad, A., Saad, D., Kacem, M., Abdelwahed, M., Khalid, D., Abderrahim, R., & Abdelhadi, A. H. (2020). Efficacy of copper foliar spray in preventing copper deficiency of rainfed wheat (*Triticum aestivum* L.) grown in a calcareous soil. Journal of plant nutrition, 43(11), 1617-1626.

Ghazi, D. A & El-Sherpiny, M. A. (2021). Improving performance of maize plants grown under deficit water stress. Journal of Soil Sciences and Agricultural Engineering, 12(11): 725-734.

Ghazi, D., Hafez, S., & Elsherpiny, M. A. (2023). Rice cultivation adaption to water resources shortage in Egypt. Egyptian Journal of Soil Science, 63(1), 113-126.

Ghouri, F., Ali, Z., Naeem, M., Ul-Allah, S., Babar, M., Baloch, F. S., ... & Shahid, M. Q. (2022). Effects of silicon and selenium in alleviation of drought stress in rice. Silicon, 14(10), 5453-5461.

Hachmann, T. L., Rezende, R., Matumoto-Pintro, P. T., Saath, R., Anjo, F. A., & Menezes, C. S. L. (2019). Yield, antioxidant activity and shelf-life of cauliflower inflorescences under drought stress and foliar spraying of selenium. Ciência e Agrotecnologia, 43, e017819.

Heyman, H., Bassuk, N., Bonhotal, J., & Walter, T. (2019). Compost quality recommendations for remediating urban soils. International Journal of Environmental Research and Public Health, 16(17), 3191.

Higashikawa, F. S., Silva, C. A., Carducci, C. E., Jindo, K., Kurtz, C., de Araújo, E. R., ... & Alves, D. P. (2023). Effects of the application of biochar on soil fertility status, and nutrition and yield of onion grown in a no-tillage system. Archives of Agronomy and Soil Science, 69(2), 212-227.

Ippolito, J. A., Tarkalson, D. D., & Lehrsch, G. A. (2011). Zeolite soil application method affects inorganic nitrogen, moisture, and corn growth. Soil science, 176(3): 136-142.

Jańczak-Pieniążek, M., Migut, D., & Piechowiak, T. (2022). The effect of exogenous copper–quercetin complex on wheat (*Triticum aestivum* L.) seedlings growth under drought stress. Chemistry Proceedings, 10(1), 18.

Juriga, M., & Šimanský, V. (2018). Effect of biochar on soil structure—Review. Acta Fytotech. Zootech, 21, 11-19. https://doi.org/10.15414/afz.2018.21.01.11-19.

Khaghani, S., Azarnivand, H., Jafari, M., Mollafilabi, A., & Tavili, A. (2020). Evaluation of different levels of zeolite and salicylic acid on some growth indices of medicinal plant (*Thymus daenensis*) under drought stress conditions. Journal of Range and Watershed Managment, 73(1), 49-63.

Khosravi Shakib, A., Rezaei Nejad, A., Khandan Mirkohi, A., & Kalate Jari, S. (2019). Vermicompost and manure compost reduce water-deficit stress in pot marigold (*Calendula officinalis* L. cv. Candyman Orange). Compost science & utilization, 27(1), 61-68.

Kurniawan, T., Nuryoto, N., & Firdaus, M. A. (2019). Zeolite for agriculture intensification and catalyst in agroindustry. World Chemical Engineering Journal, 3(1), 13-23.

Lanza, M. G. D. B., & Dos Reis, A. R. (2021). Roles of selenium in mineral plant nutrition: ROS scavenging responses against abiotic stresses. Plant Physiology and Biochemistry, 164, 27-43.

Luo, C., Yang, J., Chen, W., & Han, F. (2020). Effect of biochar on soil properties on the Loess Plateau: Results from field experiments. Geoderma, 369, 114323.

Moitazedi, S., Sayfzadeh, S., Haghparast, R., Zakerin, H. R., & Jabari, H. (2023). Mitigation of drought stress effects on wheat yield via the foliar application of boron, zinc, and manganese nano-chelates and supplementary irrigation. Journal of Plant Nutrition, 46(9), 1988-2002.

Mondal, M., Biswas, B., Garai, S., Sarkar, S., Banerjee, H., Brahmachari, K. & Hossain, A. (2021). Zeolites enhance soil health, crop productivity and environmental safety. Agronomy, 11(3): 448.

Mosa, A., El-Ghamry, A., & Tolba, M. (2020). Biochar-supported natural zeolite composite for recovery and reuse of aqueous phosphate and humate: Batch sorption-desorption and bioassay investigations. Environmental Technology & Innovation, (19): 100807.

Mostafa, M. M., El-wahed, A., Ahmed, H. M., Hamad, S. A., & Sheta, M. H. (2024). Improved water use efficiency and yield of drip-irrigated pepper under full and deficit irrigation conditions. Egyptian Journal of Soil Science, 64(2), 423-442.

Naeem, M., Naeem, M. S., Ahmad, R., Ahmad, R., Ashraf, M. Y., Ihsan, M. Z., ... & Abdullah, M. (2018). Improving drought tolerance in maize by foliar application of boron: water status, antioxidative defense and photosynthetic capacity. Archives of Agronomy and Soil Science, 64(5), 626-639.

Nawaz, F., Ahmad, R., Ashraf, M. Y., Waraich, E. A., & Khan, S. Z. (2015). Effect of selenium foliar spray on physiological and biochemical processes and chemical constituents of wheat under drought stress. Ecotoxicology and environmental safety, 113, 191-200.

Ödemiş, B., & Uncu, S. (2022). Determining effects of foliar boron applications on yield and fruit quality of apricot trees for reducing water stress. Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi, 27(1), 47-60.

Rahimi, A., Gitari, H., Lyons, G., Heydarzadeh, S., Tunçtürk, M., & Tunçtürk, R. (2023). Effects of vermicompost, compost and animal manure on vegetative growth, physiological and antioxidant activity characteristics of Thymus vulgaris L. Under water stress. Yuzuncu Yıl University Journal of Agricultural Sciences, 33(1), 40-53.

Ramadan, M. E. (2023). The impact of copper chlorophyllin on the growth, yield, and physiological characteristics of spinach plants under drought stress. Egyptian Journal of Botany, 63(3), 899-910.

Rosalina, F., Gafur, M. A., Irnawati, I., Soekamto, M. H., Sangadji, Z.,&Kahar, M. S. (2019). Utilization of compost and zeolite as ameliorant on quartz sand planting media for caisim (*Brassica juncea*) plant growth. In Journal of Physics: Conference Series (1155): No. 1, p. 012055.

Sarafi, E., Siomos, A., Tsouvaltzis, P., Therios, I., & Chatzissavvidis, C. (2018). The influence of Boron on pepper plants nutritional status and nutrient efficiency. Journal of soil science and plant nutrition, 18(3), 653-667.

Seddik, W., Osman, M. A.,& Kenawy, M. H. (2019). Physico-chemical behavior of natural minerals along with synthetic soil conditioners on nutritional status and yield productivity. Journal of Soil Sciences and Agricultural Engineering, 10(7):397-403.

Soliman, M., & Shawky, A., & Elsherpiny, M. A. (2024). Assessing the efficacy of agro-waste biochar-derived nanoparticles for purification of municipal wastewater, agricultural drainage water and industrial effluents. Egyptian Journal of Soil Science, 64(3).

Sun, Z., Hu, Y., Shi, L., Li, G., Pang, Z. H. E., Liu, S., ... & Jia, B. (2022). Effects of biochar on soil chemical properties: A global meta-analysis of agricultural soil. Plant, Soil and Environment, 68(6), 272-289.

Tahiri, A. I., Meddich, A., Raklami, A., Alahmad, A., Bechtaoui, N., Anli, M., ... & Oufdou, K. (2022). Assessing the potential role of compost, PGPR, and AMF in improving tomato plant growth, yield, fruit quality, and water stress tolerance. Journal of Soil Science and Plant Nutrition, 1-22.

Thuc, L. V., Sakagami, J. I., Hung, L. T., Huu, T. N., Khuong, N. Q., & Vu Vi, L. L. (2021). Foliar selenium application for improving drought tolerance of sesame (*Sesamum indicum* L.). Open Agriculture, 6(1), 93-101.

Tombuloglu, H., Ercan, I., Alshammari, T., Tombuloglu, G., Slimani, Y., Almessiere, M., & Baykal, A. (2020). Incorporation of micro-nutrients (nickel, copper, zinc, and iron) into plant body through nanoparticles. Journal of Soil Science and Plant Nutrition, 20, 1872-1881.

Trong, L. V., Thinh, B. B., & Phuong, H. T. (2019). Effects of copper on drought tolerance of three common bean (*Phaseolus vulgaris* L.) cultivars at seedling stage. Plant Archives, 19(2), 2911-2919.

Turfan, N. (2021). Effect of Different Organic Manures Application on the bioactive compound and yield of Taşköprü garlic (*Allium sativum* L.) under 50% drought. Uluslararası Tarım ve Yaban Hayatı Bilimleri Dergisi, 7(2), 264-275.

Wu, Q., Chi, D., Xia, G., Chen, T., Sun, Y., & Song, Y. (2019). Effects of zeolite on drought resistance and water–nitrogen use efficiency in paddy rice. Journal of Irrigation and Drainage Engineering, 145(11), 04019024.

Yadollahi-Farsani, N., Tadayon, M. R., & Karimi, M. (2021). The effect of potassium (K) and boron (B) foliar application on morphophysiological responses and root yields of Sugar Beet (*Beta vulgaris* L.) under drought stress conditions. Journal of Plant Process and Function, 10(42), 91-114.

Zahedi, H., & Moghadam, H. T. (2011). Effect of drought stress on antioxidant enzymes activities with zeolite and selenium application in canola cultivars. Research on crops, 12(2), 388-392.

الزراعة المستدامة من خلال محسنات التربة والتغذية الورقية: مراجعة مختصرة لفوائد الفحم الحيوي، الزيوليت، السماد العضوي والعناصر الدقيقة في التخفيف من آثار نقص مياه الري

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الملخص

يشكل مناخ مصر الجاف ومواردها المائية المحدودة تحديات كبيرة تعوق تحقيق الزراعة المستدامة. لمواجهة هذه التحديات، تُعد الاستراتيجيات المبتكرة ضرورية لتحسين استخدام المياه وزيادة إنتاجية المحاصيل. إن إدارة هذه القيود بفعالية أمر أساسي لتطوير ممارسات زراعية قادرة على دعم إنتاج الغذاء وتلبية احتياجات السكان المتزايدة. تستعرض هذه المقالة تأثيرات محسنات التربة مثل الفحم الحيوي والزيوليت والكمبوست، فضلاً عن التغذية الورقية التي تشمل البورون والنحاس والسيلينيوم، على نمو النباتات وجودة المحاصيل تحت ظروف الري بالتقنين والذي يعتبر استراتيجية للحفاظ على المياه تهدف إلى تقليل انخفاض المحصول مع الحفاظ على المياه، مما يستلزم تحسين تقنيات إدارة التربة والنباتات. تسلط الأبحاث الحديثة الضوء على قدرة محسنات التربة والتدخلات الغذائية على تحسين الاحتفاظ بالمياه بشكل كبير وزيادة توفر العناصر الغذائية وتعزيز قدرة النبات على تحمل الضغوط. من خلال التركيز على التعديلات العضوية مثل الفحم الحيوي والزيوليت والكمبوست، إلى جانب المعاملات الورقية للعناصر الغذائية الدقيقة الأساسية، تؤكد هذه المقالة على إمكاناتها في تعزيز كفاءة استخدام المياه وتعزيز مقاومة المحاصيل للاجهاد البيئي. تعد هذه الاستراتيجيات ضرورية لتقدم ممارسات الزراعة المستدامة، خاصة في المناطق التي تواجه ندرة المياه والتحديات المناخية. وتؤكد الدراسة الحالية على أهمية هذه الأساليب في دعم النظم الزراعية والإنتاجية، مما يساهم في نهاية المطاف في ممارسات زراعية أكثر استدامة في البيئات التي تعاني من شح المياه.