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Effects of biochar and Cosmoroot on growth characteristics and yield of soybeans

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ABSTRACT

In crop production, chemical fertilizers address nutrient deficiencies but excessive use reduces soil fertility by lowering pH and inhibiting root elongation. Biochar and Cosmoroot can be used to improve soil health, plant growth, and yield. Soybeans, vital in Zambia for food, feed, and sustainable farming, were used as a test crop due to their role in boosting the economy and enhancing soil health. The aim of this research was to determine the effects of biochar and Cosmoroot on soybean growth characteristics. The experiment was conducted at Mulungushi University as a pot experiment in a greenhouse using the randomized complete block design layout. The treatments were the control, fertilizer alone, fertilizer + Cosmoroot, fertilizer + biochar and fertilizer + biochar + Cosmoroot. The parameters measured on soybeans were: the shoot height, shoot weight, shoot diameter at the base, taproot length, number of pods, number of flowers, root weight. Analysis of variance was used to compare the means while the least significant difference test at P=0.05 was applied to identify significant differences between pairs of groups. This experiment showed that both Cosmoroot and biochar, when applied alone, were effective in enhancing the growth parameters and yield of soybean. The combination of Cosmoroot and biochar showed a negative interaction, resulting in reduced plant growth and yield. Thus, both biochar and Cosmoroot may be recommended to be applied alone in the production of soybeans.

Keywords: Biochar, plant biostimulant, Cosmoroot, Soybeans, fertilizer

INTRODUCTION

In crop production application of chemical fertilizers helps to overcome the nutrient deficiencies. Chemical fertilizers, as traditional and common fertilizers, are added at the time of planting to rapidly provide inorganic nutrients for plant growth, thereby significantly increasing crop yields. However, excess use of these chemical fertilizers reduces soil fertility by reducing soil pH disrupting the nutrient balance of farmland and inhibiting root elongation. In addition, prolonged fertilizer application destroys the chemical structure of soil humic acids, thus increasing the risk of crops being infected with pathogenic bacteria (Zhang et al., 2017). This ultimately results in soil acidification, the accumulation of pollutants in the soil, eutrophication of ground and surface water bodies, and increased greenhouse gas emissions, posing a significant threat to the environment (Huang et al., 2017; Han et al., 2021). Thus, optimizing fertilizer management is crucial for enhancing soil quality, boosting crop production, and ensuring environmental sustainability. Reducing the use of chemical fertilizers while increasing the nutrient use efficiency and replenishing soil nutrients in other ways can help to achieve sustainable agricultural production. Biochar and Cosmoroot are two different materials that can be used in crop production to improve soil health, plant growth, and yield. In recent years, both biochar and plant biostimulats have received attention worldwide due to their efficacy to boosting crop productivity and nutrient use efficiency. There are few specific studies on the combined use of biochar and biostimulants and the emerging, existing research indicates potential synergistic effects that warrant further investigation. The aim of this study was to assess the potential of biochar and Cosmoroot to improve soybean production through their complementary effects on soil fertility, nutrient availability, root growth, biomass and grain yield. Soybeans was used as a test crop because they are a vital global crop due to their high protein content, economic value, and versatility and are used in human foods, animal feed, and industrial products like biodiesel (Siamabele, 2021). As legumes, they enhance soil fertility and support sustainable farming practices. Their adaptability and diverse uses make them crucial for food security, economic growth, and environmental sustainability (Garrett et al., 2013).

LITERATURE REVIEW

Production and use of biochar in Agriculture

Biochar is a carbon-rich material that is produced through the pyrolysis of organic biomasses and has unique beneficial physical and biochemical properties (Kwaku Armah et al., 2022; Saletnik et al., 2019) such as pH, cation exchange capacity (CEC), pore size distribution, bulk density, soil structure, soil organic carbon, and soil water holding capacity. These properties are dependent on factors such as the method of pyrolysis including temperature levels and chemical composition of the substrate used (Kwaku Armah et al., 2022; Tomczyk, et al., 2020; Song and Guo, 2012).

Biochar can be produced through various methods, with the production technique significantly influencing its properties. Pyrolysis is the thermochemical conversion of biomass in an oxygen deprived environment. This process typically yields three main products: biochar, bio-oil, and syngas (Bruun et al., 2012). It is one of the most efficient methods for biochar production, with the process parameters significantly affecting the yield and properties of the final product. During pyrolysis, the natural polymers in biomass—cellulose, hemicellulose, and lignin—undergo thermal transformations (Roy and Dias, 2017). These polymers break apart, cross-link, and fragment at different temperatures (Wang et al., 2020). Slow pyrolysis favors biochar production while generating less bio-oil and syngas, whereas fast pyrolysis produces more bio-oil and syngas with a lower biochar yield (Roy and Dias (2017). The specific surface area and pore volume of biochar may be influenced by these pyrolysis processes, but factors such as maximum temperature and residence time have a greater impact (Shaheen et al., 2019). Among the most temperature-sensitive properties of biochar are surface area and pH, with pH being influenced by the thermal degradation of functional groups such as carboxyl, carbonyl, and hydroxyl at varying temperatures (Shaheen et al., 2019). Lower-temperature biochar (below 550°C) generally has a lower ash content and a less crystalline structure, which is more influenced by the type of feedstock (Gruss et al (2019). While feedstock composition largely determines the organic carbon content and mineral composition of biochar, this holds true for both plant-based and animal waste-derived biochar (Cao and Harris (2010). Yoshida et al (2008) demonstrated the variations in biochar yield due to feedstock differences by using eucalyptus wood and banagrass (Pennisetum purpureum) as feedstock. Banagrass yielded more than the eucalyptus wood.

Biochar is a suitable additive for agricultural soils as it possesses a special porous structure and neutral or alkaline pH and resists degradation making it ideal for both soil fertility improvement and carbon sequestration (Sohi et al., 2010; Lehmann and Joseph 2009). When added to soil, biochar can enhance soil fertility by adding nutrients that were previously stored in the biomass such as nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and micronutrients of Fe, Zn, Cu, Mn, B and Mo (Allohverdi et al., 2021). ~~Allohverdi et al., (2021).~~ Biochar is also known to enhance nitrogen fixation and CEC improvement (Allohverdi et al., 2021). As such, biochar may act as an organic fertilizer (Lehmann et al., 2003; Chan and Xu, 2009). Biochar's high pH, porosity, specific surface area, and cation exchange capacity can also indirectly improve soil fertility (Nepal et al., 2023; Singh et al., 2010; Yuan et al., 2011) by making nutrients more available, improving aeration and water retention, providing habitat for beneficial microbes and enhancing nutrient retention and availability respectively. Biochar's long-lasting presence in soil offers a significant advantage, reducing the need for frequent reapplication. This makes it a cost-effective solution while also acting as a stable carbon sequestration agent, as it resists complete breakdown by soil microbes and remains in the soil for years. (Mosa et al., 2023; Lehmann et al., 2021; Adeyemi and Idowu, 2017).

Production and use of biostimulants in Agriculture

On another hand, Plant biostimulants (PBs) have gained popularity for their ability to induce an array of morpho-anatomical, biochemical, physiological, and molecular plant responses. Several authors have demonstrated the efficacy of the PBs in enhancing nutrient use efficiency (NUE), tolerance against abiotic stresses and boosting crop productivity (Rouphael Colla, 2020). Abiotic stresses like drought, salinity, and extreme temperatures significantly impact plant growth and productivity are a problem of concern for the growth and productivity of plants in modern times (Carolina Feitosa de Vasconcelos and Helena Garófalo Chaves, 2020; Singh and Takhur, 2018). To mitigate these effects, biostimulants are increasingly used in production systems to modify plant physiological processes and optimize yield. PBs are defined as any substance or microorganism applied to plants with the aim of improving NUE, abiotic stress tolerance, and/or crop quality traits, regardless of its nutrient content (du Jardin, 2015). Biostimulants can be classified by their mode of action and origin (Basak et al., 2008), their effects on plants (Bulgari etal 2015), or their impact on productivity, emphasizing their agricultural functions (du Jardin, 2015). Thus, by using biostimulants, biological function can be positively modulated through the application of molecules, or mixtures of molecules, for which an explicit mode of action has not been defined. Biostimulants, made from natural or synthetic substances with hormones or their precursors, enhance plant growth, development, and stress tolerance when properly applied (Carolina Feitosa de Vasconcelos and Helena Garófalo Chaves, 2020). Cosmoroot is a PB that contains phosphorus, potassium, free L-amino acids, and organic extracts formulated to stimulate root formation and development (Rouphael and Colla, 2020; Colla and Rouphael, 2015). Thus, Cosmoroot is purported to induce root formation and development thereby help to improve crop yield through improved nutrient uptake caused by improved root development.

Combined use of biochar and biostimulants

A few studies has explored the combined use of biochar and biostimulants, revealing synergistic benefits for plant growth and soil health. A study by Antón-Herrero et al (2022) on pepper plants grown in contaminated soils demonstrated that this combination decreased the bioavailability of cadmium, reducing its uptake by the plants. This approach proved advantageous in scenarios of nutrient scarcity and contamination, enhancing plant production. Additionally, since biochar application has been shown to improve soil fertility and plant productivity. A meta-analysis of 153 studies by Dai et al., (2020) highlighted that biochar's effectiveness depends on its properties and soil conditions, suggests that combining biochar with biostimulants could further optimize plant growth and yield.

METHODOLOGY

The experiment was conducted at Mulungushi University located 26km north of Kabwe town. It's located at a Longitude of 28°33′36″E, Latitude14°17′42″S and an altitude of 1,182 meters above sea level. It lies in Agro-Ecological zone II which receives rainfall between 800 to 1000mm.

The experiment was carried out in a greenhouse in plastic pots measuring 10 litres each. Each pot was filled with 11.5kg soil. The treatments comprised (1) control, (2) fertilizer alone, (3) cosmoroot +fertilizer, (4), Biochar + Fertilizer (5) Biochar + Cosmoroot+ Fertilizer. These were replicated 8 times making 40 pots. These were arranged in a randomized complete block design (RCBD). The biochar was applied at the rate of 2% of soil weight (234.69g) and was thoroughly mixed in the soil. The 10:20:10 (NPK) fertilizer compound was applied at 200t/ha rate equivalent. The fertilizer application was done a week after planting. Five (5) soybean seeds were planted per pot and thinned to 4 plants after germination. The soybeans were planted after being inoculated with *Bradyrhizobium japonicum* (NITROZAM) strain of bacteria inoculant following the procedure outlined on the packet label. Cosmoroot was applied two times: first dose was applied two weeks after germination and the second dose, three weeks after germination by drenching the soil with the mixture. The planting date was 16th of Feb 2022.

Plant growth characteristics of shoot length, taproot length, and shoot diameter at the base was measured/calculated from the circumference measured at the base using a string and a tape rule (diameter= C/π); the shoot length was taken from the plant base to the upper most shoot tip. Number of pods per plant was determined by counting pods from each plant; root weight and shoot weight was determined using a mass balance.

On the 10th and 17th March 2022, plant height and the number of leaves on the plant were measured for all the plants. On 24th March, measurements included: leaf length (LL) of 3rd and 4th leaves from the base. On the 31st March, measurements were taken for the LL of the 4th and 5th leaves, number of branches (BN), number of flowers (FN), shoot weight (SW), root weight (RW), and plant weight (PW) in four replication of the treatments. On 7th April, we measure the leaf length (LL) of the 5th and 6th, leaves, BN, FN, SW, RW and PW in four replicates. On the 14th April, we measured the LL of the 6th and 7th leaves and the BN, FN, SW, RW, PW, pod number (PodN) and shoot diameter (SD) in four replicates of the pots which had not been tempered with.

For the measurement of the SW, RW, PW, SD, the plants were destructively harvested. The plants were uprooted carefully under excessive running water removing the soil from the roots. The plants were carefully wrapped in a news paper and oven dried at 105^{0} C for 72 hours. The PW, SW and RW were measured using an analytical balance (0.0001g to 220g) CA-224 Contech Instruments Ltd. The shoot and the root weight were separated by cutting the shoot at the base where the shoot emerges from the soil. The grain harvesting was done by hand, approximately 130 days after sowing when the crop started drying (passed physiological maturity). The grain weight was determined after air-drying for two weeks followed by a 48hrs of oven drying at 40^{0}C.

One-way analysis of variance (ANOVA) was used using SPSS software to analysing the means using the least significant difference test (LSD) at 5% level of significance was used to identify significant differences between group pairs.

RESULTS

The effect of cosmoroot and biochar on the growth parameters and yields in soybean

The effect of biochar and Cosmoroot on the growth characteristics and yield of soybeans was varied depending on the parameter. Apart from shoot diameter and number of leaves, the effect of the treatment was significantly different from the control in all the parameters. In the number of leaves, cosmoroot, biochar, and the combination (Cosmoroot + biochar) treatments, were significantly different from the control and the fertilizer alone treatments, but not significant among the treatments. In the shoot diameter, the Cosmoroot treatment was significantly different from the control and the combination treatment only while the combination treatment was significantly different from all other treatments. Comparing the effect of biochar, cosmoroot and the combination treatments, all other parameters showed no statistical significant difference. Notwithstanding the non-significant results, there were varied notable differences in the means of the measured parameters among the treatments. The results showed that Cosmoroot was more effective in improving shoot height leaf length, shoot weight, root weight, plant weight, number of pods and the shoot diameter of Soybeans compared to biochar treatment. The biochar treatment only scored highest in the number of flowers and the number of branches. In all the parameters except for the number of leaves and shoot diameter, the mean for all the parameters was lowest in the combination treatment. Grain yield in the combined treatment recorded a notable reduction of 42.7% and 33.2% compared to biochar and Cosmoroot treatments when applied alone respectively. Other parameters that the combined treatment reduced compared to biochar and Cosmoroot when applied alone included the number of flowers by 30.3% and 17.8%, shoot weight by 23.3% and 26.5%, root weight by 17.5% and 25.2% and 100 seed weight by 8.6% and 3.8 % respectively. In root weight and grain weight, fertilizer alone produced the highest yield. Comparing the fertilizer alone with Cosmoroot, biochar and the combination treatments, the root weight, showed 11.6%, 20.1% and 33.9% reductions while the grain weight showed 15.8%, 1.8% and 43.8% reductions respectively. These show that the treatments had an inhibiting effect in the root and grain yields with the combination treatment being the worst performing treatment caused 33.9% and 43.8% loses in the two parameters compared to fertilizer alone. Surprisingly the 100 seed weigh was highest in the control followed by the biochar treatment though they were not significantly different from rest of the treatments. Table 1 and the figure 1 (I-X) shows the differences in the measured parameters across treatments.

Table 1: The table shows differences in means and standard deviations of the measured parameters of soybeans among treatments

Treatment / Parameters	Control	Fertilizer	Cosmoroot (+ Fertilizer)	Biochar (+ Fertilizer)	Cosmoroot + Biochar (+ Fertilizer)
Shoot height (cm)	$56.3\pm9.2_{a}$	$83.8\pm16.7_{b}$	$99.4\pm10.7_{c}$	$96.5\pm5.5_{bc}$	$94.8\pm5.9_{bc}$
Number of leaves	$11\pm1.4_{a}$	$14.3\pm2.6_{ab}$	$19.3\pm5.5_{b}$	$20\pm4.2_{bc}$	$21\pm2.5_{bc}$
Ave Leaf length 3-7 (cm)	$18.7\pm2.1_{a}$	$27.9\pm3.5_{b}$	$30.3\pm2.8_{b}$	$30.2\pm3.9_{b}$	$28.8\pm2.1_{b}$
Number of branches	$2\pm0.8_{a}$	$3\pm0.8_{b}$	$4\pm0.5_{b}$	$4\pm0.8_{b}$	$3.8\pm0.9_{b}$
Number of flowers	$6.8\pm1.3_{a}$	$10\pm5.5_{b}$	$14\pm4.8_{b}$	$16.5\pm3.7_{b}$	$11.5\pm8.4_{b}$
Shoot weight (g)	19.9	43.2	55.8	53.6	41.1
Root weight (g)	6.7	22.4	19.8	17.9	14.8
Plant weight (g)	26.6	65.6	75.6	71.5	55.9
Number of pods	$9\pm3.6_{a}$	$14.3\pm10.7_{b}$	$26.8\pm6.1_{c}$	$26\pm5.7_{c}$	$20\pm6.2_{bc}$
Shoot diameter (cm)	$1.9\pm0.3_{a}$	$2.2\pm0.2_{ab}$	$2.5\pm0.3_{b}$	$2.2\pm0.3_{ab}$	$2.6\pm0.3_{bc}$
Grain Weight (g)(t/Ha)	26.6 (1.66)	49.8 (3.11)	41.9 (2.62)	48.9 (3.06)	28.0 (1.75)
100 Seed Weight (g)	14.15	13.64	13.14	14	12.82

Values of means ± Std. deviation, F-value and the significance **level** for each parameter.
Subscripts a,b,c indicates significant differences among the parameter averages at $P<0.05$

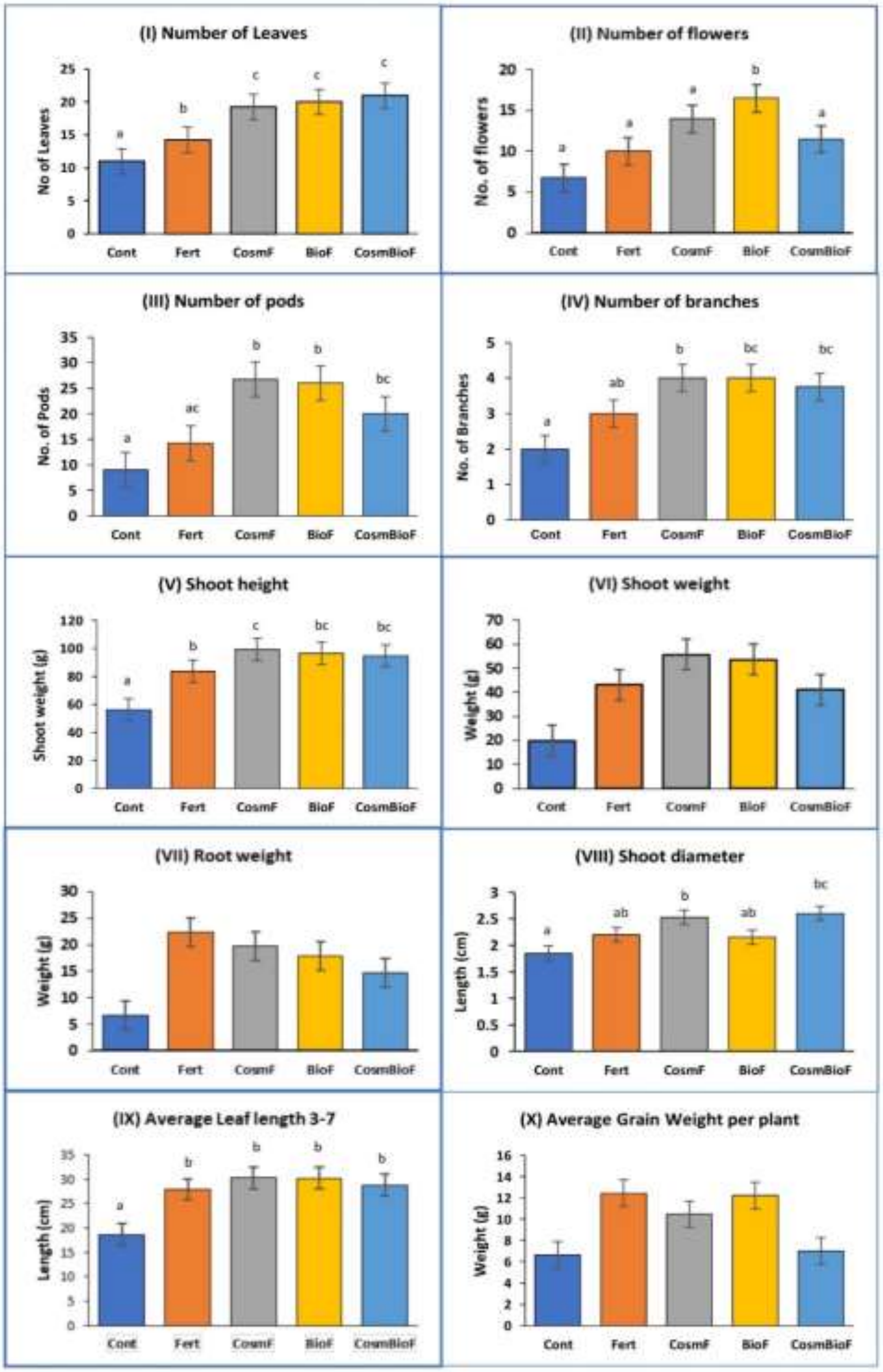

Figure 1: Showing differences in means and standard deviations of different growth parameters among treatments.

DISCUSSION AND CONCLUSION

The effect of Cosmoroot and biochar on the growth parameters in soyabeans

Cosmoroot and biochar showed positive effects on a number of growth parameters of soybeans. Even though there were no statistical differences in the parameters between Cosmoroot and biochar treatments, the results showed that Cosmoroot plus fertilizer was more effective in improving root weight, shoot height and weight, leaf length, number of pods and the shoot diameter of soybeans compared to biochar plus fertilizer treatment. Cosmoroot is a biostimulant which is supposed to be used in conjunction with a regular feeding plan, which provides the necessary nutrients for plant growth. Cosmoroot enhances plant growth and yield by significantly improving root architecture and function. It increases nutrient absorption capacity through enhanced root length and biomass (Calvo et al., 2014; Pierezan et al., 2012). Additionally, it induces modifications in root configuration, such as elongation of the primary root, expansion of the lateral root system, and structural improvements in root hairs (Rao et al., 2016; Qin et al., 2021). These changes optimize nutrient and water uptake, directly contributing to better plant growth and higher yields. Thus, Cosmoroot by increasing the root density expressed as root weight and probably root length enhanced the plant's ability to absorb and utilize the available water and nutrients, leading to enhanced growth in the above parameters and yield.

On the other hand, biochar plus fertilizer was more effective in increasing the number of leaves, number of flowers, number of branches and grain weight compared to Cosmoroot plus fertilizer treatment or the combination of Cosmoroot and biochar plus fertilizer treatments. Biochar is known for increasing the soil fertility (Lehmann et al., 2009, Dari et al., 2016; Nair et al.. 2017) and improving soil water and nutrient-holding capacity and preventing leaching of plant nutrients (Jeffrey et al., 2017) thereby improving plant nutrients uptake. By this mechanism, biochar has the ability to increase the plant growth characteristics. Thus, the application of Cosmoroot (plus fertilizer) alone led to increased plant growth parameters and yield, and the application of biochar (plus fertilizer) alone equally led to increased plant growth and yield with the results showing no significant differences in the investigated growth parameters between treatments. However, in comparison with Cosmoroot, biochar treatment was more effective in the production of flowers, grain weight and 100 seed weight only. Biochar by improving soil water and nutrient-holding capacity and preventing leaching of plant nutrients and consequently improving plant nutrients uptake could be responsible for increasing the production of flowers and grain weight.

The combination treatment of Cosmoroot and biochar treatments led to an additive, or synergistic interaction in improving the number of leaves and the shoot diameter. This increase in the number of leaves has the potential to produce a positive effect on grain yield, shoot weight, number of pods, shoot weight, and root weight (Jones et al. 2019; Smith et al. 2018) since leaves are the primary site of photosynthesis in the plant and play a critical role in providing energy for growth and development. However, in our experiment, the combined treatment showed a reduction in number of flowers and pods, root, shoot and grain weight, contrary to the above expectation. This negative priming of the treatments could be due to some antagonistic interactions between Cosmoroot and biochar. Cosmoroot supports root development at optimal levels; however, excessive application or interactions with biochar can result in imbalanced root growth, altering resource allocation and reducing yield potential (Santos et al., 2022). According to Santos et al., (2022), this imbalance often causes plants to allocate excessive reserves to root development, detrimentally affecting shoot growth and yield. Such resource misallocation can compromise overall plant productivity and highlight the need for precise management of biochar and Cosmoroot applications to maintain optimal balance.

Meta-analyses by Jeffery et al. (2011) and Biederman and Harpole (2013) revealed that biochar's effects on crop productivity are context-dependent, with some studies documenting negative crop responses (e.g., Wisnubroto et al., 2010; Calderón et al., 2015; Knox et al., 2015). To address this variability, combining biochar with non-pyrolyzed organic amendments (such as compost, manure, plant litter etc.) and biostimulants has been proposed as a potential strategy to enhance its effectiveness (Bonanomi et al., 2017). However, current research on this combined approach is limited, and further studies are needed to better understand its impact and optimize its use. Thus, field-specific research is critical to determine the optimal application rates and combinations of biochar and Cosmoroot to minimize the risk of excessive application. Tailored practices can maximize their synergistic benefits while minimizing adverse effects on crop yield and soil health.

These studies and ours, suggest that the interaction between Cosmoroot and biochar can be complex and context-dependent, and that the combined application of these treatments may not always lead to positive outcomes. It is important to conduct further research to better understand the mechanisms behind these interactions and to identify the conditions under which they occur.

CONCLUSION

The study found that both Cosmoroot and biochar, when applied alone, were effective in enhancing the growth parameters and yield of soybean plants. The combination of Cosmoroot and biochar showed a negative interaction resulting in reduced plant growth and yield, contrary to the expected positive effects. These findings suggest that the interaction between Cosmoroot and biochar can be complex and context-dependent and require further research to better understand the underlying mechanisms and conditions. Overall, the study highlights the potential of using bio-stimulants and biochar for enhancing plant growth and yield, but also underscores the importance of carefully considering the interactions between different treatments in designing effective and sustainable agricultural practices.

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