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Enriched Ameliorant and Readily Available Nutrients for Enhancing the Rhizobacterial Population, Nutrient Uptake, and Yield of Pepper Grown in Inceptisol Soil Media: A Review

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ABSTRACT: Soil fertility affects the diversity and quality of soil microbes in decomposing organic matter and recycling nutrients. Inceptisols soil is young soil that is starting to develop with its soil fertility status. Management is needed to maximize sustainable soil quality and high plant productivity. Chili plants are widely cultivated but suboptimal soil conditions can inhibit plant growth. Ameliorant materials can be organic or inorganic materials. Ameliorant provides benefits in reducing damage, maintaining nutrients in the soil, increasing the organic nutrient content in the soil and helping microbial symbiosis. The efficiency of nutrient use depends on the plant's ability to absorb nutrients. The effectiveness of nutrient management strategies by combining inorganic and organic nutrient inputs, it is proven that balanced nutrient management can increase plant growth and productivity. Ameliorant can come from organic and inorganic materials which can increase soil fertility from biological and chemical properties, the productivity of chili plants. The materials used as ameliorant are biochar, biosolids, animal waste, microalgae. When cultivating chilies in inceptisol media, it is necessary to apply ameliorant combined with effective essential nutrients, in order to increase chili productivity and contribute to agricultural agriculture.

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INTRODUCTION

Agriculture is one area of important concern because of the many SDGs goals included in it, requiring agroecosystem management to maximize the efficiency of agricultural systems in order to increase the role of soil ecosystems such as absorbing carbon and reducing greenhouse gas emissions (Gogoi et al., 2024). Sustainable agriculture is the best choice to reduce the use of chemical fertilizers and pesticides by using a mixed cropping system and utilizing organic materials such as manure and other agricultural waste as organic fertilizer (Niemmanee et al., 2015). Soil health is the ability of soil to continue to function as an ecosystem that supports vital life for plants, animals and humans. Soil fertility is influenced by the diversity and quality of soil microbes in decomposing organic matter and recycling nutrients (Jose et al., 2024). Sustainable evaluation of land management practices can be carried out by monitoring soil health indicators periodically (Nunes et al., 2020). Collaborative efforts are made to protect natural resources to maintain agriculture, food availability and minimize negative impacts on the environment (Saha & Bharadwaj, 2023).

Inceptisols soil is a young soil that is starting to develop with its soil fertility status having relatively high soil acidity, very low CEC content, base saturation, P-total, and K-total as well as low C-organic content (Lubis & Sebayang, 2024). Management is very necessary to maximize sustainable soil quality and high plant productivity, one of which is the application of ameliorants and the provision of available elements (Agbede & Oyewumi, 2022). Chili (*Capsicum annum* L.) is widely cultivated because of its high market demand and economic value, however suboptimal soil conditions can inhibit plant growth and reduce assimilate production in chilies (Widuri et al., 2020). Chili harvest results are influenced by cultivation techniques which include increasing the amount of ideal fertilizer, the absorption of elements by plants, growth regulators and so on. Before reaching the flower and fruit production phase, vegetative growth in the stems and leaves of chilies needs to be provided with nutrients that help the photosynthesis process (Fatima et al., 2023).

Ameliorant Ingredients and Their Benefits for Soil Health

Soil amendment (ameliorant) provides benefits in reducing damage, securing nutrients in the soil, and helping microbial symbiosis (Ahn et al., 2022). Microorganisms in soil require renewable organic material for enzyme activity which is closely related to soil microbial populations and soil fertility (Chen et al., 2024). The application of bio-organic ameliorants to soil has a positive impact on environmental stress conditions by reducing dissolved salt content and sodium levels in the soil, as well as improving soil fertility containing high levels of salinity and acidity (Hafez et al., 2022).

Organic ameliorants made from microalgae mixed with biostimulants can support plants in rehabilitated land by increasing the organic nutrient content in the soil and strengthening the soil microbiome and helping plants deal with drought conditions (Levett et al., 2023). The use of organic waste or animal waste residue is often used as a soil amendment in agroecosystems because it contains nutrients that support the growth of various soil microorganisms, improving the health and quality of the soil in plant cultivation (Ezeokoli et al., 2023).

Another study states that biochar can also be used as an ameliorant material because it increases the number of bacteria in the soil by encouraging the degradation of petroleum hydrocarbons by influencing the number of microorganisms in the soil as well as the transport and biodegradation of pollutants (Ruseva et al., 2024). Other research also states that biochar can inhibit N emissions, increase grain yield, and help carbon sequestration (Liu et al., 2024). Another material that can be used as a soil amendment is biosolids which have the potential to replace synthetic fertilizers by meeting the nitrogen and phosphorus needs in agriculture, helping to restore the fertility of agricultural soil due to its use fertilizer haphazard synthetic, degraded soil at mining sites (Silva-Leal et al., 2021).

In agricultural applications, organic fertilizers such as manure and vermicompost can be combined with biochar to increase the efficacy of biochar in improving soil function, increasing crop yields in subtropical conditions (Sharma et al., 2021). Also supported by other research on biochar, this material can be a soil improver because it can optimize the nitrogen and phosphorus metabolic cycle in plants in contaminated soil (Ran et al., 2023).

Apart from being applied with organic fertilizer, there are also studies that show that biochar can be combined with inorganic/synthetic NPK fertilizer which has an impact on soil chemical properties such as increasing soil pH, cation exchange capacity (CEC), absorption and efficiency of nitrogen, phosphorus and potassium as well as increasing corn seed yields (Phares et al., 2022). In the cultivation of chili plants, research was also carried out on biochar combined with organic materials derived from chicken waste, and the results were obtained that it could increase productivity carbon absorption in the soil and provide enough nutrients (Majeed M. Ali Jaaf et al., 2022).

Diversity Soil microbes such as bacteria, fungi, protozoa and algae are indicators of soil fertility, usually the number of bacterial colonies will be greater at neutral pH because they influence physiological processes which ultimately affect the microbial community in the plant rhizosphere (Pathak et al., 2022). Bioameliorant can be specially formulated so that it contains several good microbes that function in the rhizosphere, such as *Bacillus, Bacillariophyta, Bacteroidetes, Basidiomycota, Chloroflexi, Chlorophyta, Firmicutes, Planctomycetes, Proteobacteria* which can dissolve nutrients and make a major contribution to soil fertility (Jose et al., 2024). Rhizobacteria are natural microorganisms that live in soil and are able to colonize the plant root system directly as a growth regulator (ZPT) for plants (Zarpelon et al., 2016). Bacteria from PGPR have an impact that promotes growth and significantly improves plant quality, as well as the potential for good application in plant cultivation, so that it can contribute to environmental protection and economic growth (Zhang et al., 2024).

Ameliorants and Nutrients in Increasing Chili Plant Productivity

Appropriate cultivation practices such as regulating water, quantity and nutrient concentration solutions through determining EC values and adding NaCl compounds can be carried out to improve nutritional quality (Ou et al., 2023). The efficiency of nutrient use depends on the ability of plants to absorb nutrients from the soil and the ability of the soil to provide sufficient nutrients for growth, development and formation of plant results (Kebede et al., 2024). An abundance of soil microorganisms promotes root growth and nutrient uptake. Studies also explain that bacterial and fungal communities in double cropping systems have varying sensitivities and assembly mechanisms along K fertilizer gradients on corn and wheat crop yields (Z. Li et al., 2024).

In order to support the effectiveness of nutrient management strategies by combining inorganic and organic nutrient inputs, it has been proven that balanced nutrient management can increase plant growth and productivity (Begam et al., 2024). In solving this problem, information was obtained that the use of organic fertilizer combined with mycorrhizal inoculation (*Azotobacter chroococcum* + *Azospirillum lipoferum*) can increase the productivity and quality of chilies grown in greenhouse conditions (Nejati Sini et al., 2024). PGPR plays a role in changing the physiology of the entire plant, thereby increasing nutrient absorption and influencing the effectiveness of root activity (Khoso et al., 2024).

Nitrogen is an essential nutrient that influences plant growth and physiology as the main component of amino acids, proteins, nucleic acids and chlorophyll. A high supply of nitrogen reduces carbon assimilation and the C/N ratio, and has a positive influence on the efficiency of water use by plants (Yang et al., 2022). Excessive addition of nitrogen in agriculture is a source of emissions for global warming, reduced biodiversity, and depletion of non-renewable phosphate resources (Kashyap et al., 2023). Ameliorants derived from biochar combined with aminos have an impact on soil fertility, nutrient uptake and photosynthesis to increase crop yields (H. Li et al., 2023).

In chili cultivation, nitrogen fertilizer must be combined with charcoal so that chili growth and yield require a combination of nitrogen fertilizer 100 kg ha^{-1} + 2,5% charcoal based on soil weight to increase microbial activity soil, increasing N availability, and increasing crop yields (Subedi et al., 2023). Providing liquid nutrition can be organic with the advantage that it produces lower nitrate levels and higher levels of total chlorophyll, carotene, phenolics and flavonoids in organically grown lettuce. This indicates a higher antioxidant capacity and nutritional value for human consumption (Alneyadi et al., 2024).

CONCLUSION

Soil amendment or ameliorant is a technology in the agricultural sector, especially in soil derived from organic and inorganic materials which can increase soil fertility from biological and chemical properties, productivity of chili plants. Materials that can be used as ameliorant are biochar, biosolids, animal waste, microalgae. When cultivating chilies in inceptisol media, it is necessary to apply ameliorant combined with effective essential nutrients, in order to increase chili productivity and contribute to sustainable agriculture.

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