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Physical and Chemical Properties of Soil in Vegetable Fields After Compost Application

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Abstract

The degradation of soil physical and chemical properties in intensive vegetable cultivation systems necessitates effective and sustainable amelioration strategies. This study aimed to examine the effect of compost dosage on soil Bulk Density, nitrogen, phosphorus, and potassium in vegetable land. The study employed a Randomized Block Design (RBD) with three compost dosage treatments (P0 = 0 ton ha^{-1}, P1 = 15 ton ha^{-1}, P2 = 30 ton ha^{-1}) and three replications. The measured parameters included Bulk Density (BD), total nitrogen (N), available phosphorus (P), and exchangeable potassium (K). Data were analyzed using ANOVA followed by Duncan's Multiple Range Test (DMRT) at the 5% significance level. Results indicated that compost application significantly affected all tested parameters. Bulk Density decreased significantly from 1.44 g cm^{-3} (P0) to 1.28 g cm^{-3} (P2). Total nitrogen increased from 0.15% (P0) to 0.21% (P2). Available phosphorus increased very significantly from 7.71 ppm (P0) to 11.53 ppm (P2), while exchangeable potassium increased from 0.13 cmol kg^{-1} (P0) to 0.29 cmol kg^{-1} (P2). The P2 treatment (30 ton ha^{-1}) was the most effective dosage for restoring soil physical and chemical quality in intensive horticultural systems.

Keyword: Bulk Density. Macronutrients. Horticultural Systems, Organic Fertilizer

INTRODUCTION

Intensive vegetable cultivation systems face serious challenges in the form of soil quality degradation resulting from unsustainable agricultural practices. Excessive soil tillage, short crop rotations, and high inorganic fertilizer application cause deterioration of soil structure, increased Bulk Density, and decreased organic matter content and essential nutrients (Lal, 2015). These

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conditions directly impact land productivity and the sustainability of horticultural production systems.

Soil organic matter plays a fundamental role in maintaining soil ecological functions, including particle aggregation, nutrient regulation, and microbiological activity (Brady & Weil, 2017). Compost application as a soil amendment has proven effective in improving soil quality through enhancement of soil physical, chemical, and biological properties (Suddick et al., 2013). Compost provides carbon substrate for soil microorganisms, increases cation exchange capacity, and contributes to gradual nutrient release through mineralization processes.

Previous research has demonstrated that organic matter application can reduce Bulk Density and increase soil porosity (Brady & Weil, 2017). Nitrogen mineralization from organic matter occurs through decomposition of protein compounds and amino acids by heterotrophic microorganisms (Stevenson, 1994). Meanwhile, phosphorus and potassium availability is influenced by the complex interactions of mineral dissolution, ion desorption from colloidal surfaces, and soil pH dynamics (Havlin et al., 2014). Nevertheless, empirical studies comprehensively examining soil physical and chemical property responses to compost dosage gradients in vegetable cultivation systems with rigorous experimental design remain limited.

This study aimed to analyze the effect of compost dosage on Bulk Density, total nitrogen, available phosphorus, and exchangeable potassium in vegetable land soil, and to determine the most effective application dosage for restoring soil quality.

METHOD

Time and Location

The study was conducted on intensively used vegetable land. Laboratory analyses included Bulk Density measurement using the core method, total nitrogen using the Kjeldahl method, available phosphorus using the Bray-1 method, and exchangeable potassium using the NH_4OAc 1 N pH 7.0 extraction method following standard soil analysis procedures (Brady & Weil, 2017).Data processing The data processing stage is to create a Mamdani fuzzy system using Matlab software.

Experimental Design

The study employed a factorial Randomized Block Design (RBD) with three compost dosage treatments and three replications, resulting in nine experimental units. The tested treatments were:

P0: Control (0 ton ha^{-1})

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P1: Compost 15 ton ha^{-1}
P2: Compost 30 ton ha^{-1}
The compost used was mature compost derived from agricultural organic waste with a C/N ratio <20. Compost application was conducted uniformly in each treatment plot and incorporated into the soil to a depth of 20 cm.

Observed Parameters

The measured parameters included: (1) Bulk Density (g cm^{-3}), (2) Total nitrogen (%), (3) Available phosphorus (ppm), and (4) Exchangeable potassium (cmol kg^{-1}). Soil sampling was conducted at 0-20 cm depth following a 90-day incubation period after compost application.

Data Analysis

The obtained data were analyzed using Analysis of Variance (ANOVA) at a 5% significance level. When significant effects were detected, Duncan's Multiple Range Test (DMRT) at the 5% level was performed to compare treatment means using statistical analysis software.

RESULTS AND DISCUSSION

Bulk Density

Analysis of variance revealed that compost dosage treatment significantly affected soil Bulk Density ($p = 0.0057$). Bulk Density reduction followed a linear pattern with increasing compost dosage. The control treatment (P0) exhibited the highest Bulk Density value of 1.44 g cm^{-3}, indicating relatively high soil compaction. Application of 15 ton ha^{-1} compost (P1) reduced Bulk Density to 1.38 g cm^{-3}, though statistically not significantly different from the control. The most significant reduction occurred in the P2 treatment (30 ton ha^{-1}) with a value of 1.28 g cm^{-3}, which differed significantly from both other treatments based on DMRT.

Total Nitrogen

Soil total nitrogen content was significantly influenced by compost application ($p = 0.0170$). The nitrogen increase trend followed the gradient of applied compost dosage. Control soil had the lowest nitrogen content (0.15%), indicating nutrient depletion due to intensive cultivation systems without organic matter input. Application of 15 ton ha^{-1} compost increased total nitrogen to 0.20%, while the 30 ton ha^{-1} dosage resulted in 0.21% nitrogen content. Follow-up DMRT indicated that P1 and P2 treatments were not significantly different from each other, but both differed significantly from the control.

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Available Phosphorus

Available phosphorus showed a highly significant response to compost application (p = 0.0013), with a consistent increase pattern following dosage increment. The control treatment produced the lowest phosphorus content (7.71 ppm), classified in the low category for optimal horticultural production. Application of 15 ton ha^{-1} compost increased available phosphorus to 10.19 ppm, while the 30 ton ha^{-1} dosage produced the highest content of 11.53 ppm. DMRT results indicated that all three treatments differed significantly from each other, demonstrating a clear dosage effect on phosphorus availability.

Exchangeable Potassium

Exchangeable potassium also showed a significant response to compost dosage (p = 0.0052). The potassium increase pattern followed the same trend as other chemical parameters. Control soil had the lowest potassium content (0.13 cmol kg^{-1}), while application of 15 ton ha^{-1} compost increased the value to 0.24 cmol kg^{-1}. The highest dosage (30 ton ha^{-1}) produced a potassium content of 0.29 cmol kg^{-1}. Based on DMRT, treatments P1 and P2 were not significantly different, but both differed significantly from the control.

Table 1. Effect of compost dosage on soil physical and chemical properties

Parameter	P0 (0 ton ha^{-1})	P1 (15 ton ha^{-1})	P2 (30 ton ha^{-1})	P-value
BD (g cm^{-3})	1.44^{a}	1.38^{a}	1.28^{b}	0.0057*
N total (%)	0.15^{b}	0.20^{a}	0.21^{a}	0.0170*
P available (ppm)	7.71^{c}	10.19^{b}	11.53^{a}	0.0013**
K-exch (cmol kg^{-1})	0.13^{b}	0.24^{a}	0.29^{a}	0.0052*

Note: Values followed by different superscript letters within the same row indicate significant differences based on DMRT 5%; * = significant; ** = highly significant; BD = Bulk Density; K-exch = exchangeable potassium.

DISCUSSION

Improvement of Soil Physical Properties: Bulk Density Reduction

The significant Bulk Density reduction in the high-dose compost treatment (P2) reflects soil structure improvement through enhanced aggregation and porosity. Brady and Weil (2017) explain that organic matter functions as a binding agent for mineral particles through physical

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enmeshment and chemical bonding mechanisms, forming stable aggregates resistant to compaction. Compost provides carbon substrate for microbial activity that produces polysaccharide exudates and other sticky compounds, which serve as cementing agents between soil particles.

The reduction in Bulk Density from 1.44 g cm^{-3} to 1.28 g cm^{-3} has significant practical implications for soil hydrological function and aeration. Soil with lower Bulk Density has larger pore space, facilitating water infiltration and gas exchange required for root respiration and soil microbial activity (Lal, 2015). In vegetable cultivation systems requiring good drainage and optimal aeration, Bulk Density improvement through compost application becomes an effective amelioration strategy to address compaction problems resulting from intensive soil tillage.

Increased water infiltration and retention, improved root penetration, enhanced soil aeration, and better overall soil structure. By reducing bulk density, soil physical properties are optimized, leading to healthier and more productive soils. This ultimately results in improved crop yields, better water management, and increased soil resilience to environmental stressors. Overall, the reduction of bulk density is crucial for maintaining soil health and sustainability in agricultural systems (Cárceles et al., 2022) . Proper management practices, such as reduced tillage and cover cropping, can help in achieving lower bulk density levels in the soil. These practices not only improve soil physical properties but also contribute to long-term soil health. Farmers who prioritize reducing bulk density in their fields are more likely to see increased profits and sustainability in their agricultural operations. In conclusion, the benefits of bulk density reduction extend far beyond just improved crop yields, making it a key component of successful farming practices (Wei, 2019).

Improved root growth and plant nutrient uptake are just a few of the additional benefits that come from implementing practices to reduce bulk density in soil. By creating a more favorable environment for roots to grow and access essential nutrients, farmers can expect to see healthier plants with higher yields. Additionally, lower bulk density can help improve water infiltration and retention, reducing the risk of erosion and water runoff (Kopila et al., 2019) . Overall, the positive impacts of managing bulk density in soil highlight the importance of sustainable and regenerative farming practices for the long-term success of agriculture. By increasing soil health through practices like reduced tillage and cover cropping, farmers can further enhance the benefits of managing bulk density. These practices not only help to improve soil structure and organic matter content, but also promote biodiversity and beneficial soil microorganisms (Johan, 2023).

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Total Nitrogen Increase Through Organic Matter Mineralization

The increase in total nitrogen in compost treatments reflects direct contribution from organic nitrogen in compost as well as mineralization processes occurring after application. Stevenson (1994) explains that organic nitrogen in compost exists in various forms, including proteins, amino acids, nucleic acids, and complex heterocyclic compounds. Transformation of organic nitrogen into inorganic forms available to plants occurs through a series of enzymatic processes catalyzed by heterotrophic microorganisms.

Nitrogen mineralization processes are influenced by organic matter quality, particularly C/N ratio and lignin content. Mature compost with low C/N ratio tends to undergo mineralization more rapidly compared to raw organic matter, making nitrogen available faster for plants (Havlin et al., 2014). The increase in total nitrogen from 0.15% to 0.21% in the P2 treatment indicates that the 30 ton ha^{-1} dosage can substantially increase the soil organic nitrogen pool, which will contribute to long-term nitrogen supply through gradual mineralization.

The results of study provide valuable insights into the factors influencing nitrogen mineralization rates and total nitrogen increase in different organic matter types. The presentation of total nitrogen increase data highlights the significant role of organic matter in nitrogen cycling and its impact on nutrient availability in soil (Katherine et al., 2023) . The comparison of nitrogen mineralization rates across various organic matter types further emphasizes the importance of understanding the complex interactions between soil properties and microbial activity. Overall, this study contributes to our understanding of nitrogen dynamics in soil ecosystems and provides a foundation for future research in this field. The findings suggest that the rate of nitrogen release from organic matter is influenced by factors such as carbon content, lignin composition, and microbial populations (Vera & Helen, 2007) . By studying these relationships, researchers can better predict nutrient availability and tailor management practices to optimize soil health. Additionally, this research underscores the need for sustainable agricultural practices that promote organic matter decomposition and nutrient cycling to maintain soil fertility in the long term. Ultimately, a deeper understanding of nitrogen dynamics in soil ecosystems is essential for promoting sustainable agriculture and preserving environmental quality.

Available Phosphorus Dynamics and Release Mechanisms

The highly significant and dose-dependent increase in available phosphorus demonstrates the complexity of mechanisms involved in soil phosphorus dynamics following

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compost application. Phosphorus in compost can exist in organic forms (phytate, phospholipids, nucleic acids) and inorganic forms, both of which contribute to increased phosphorus availability in soil (Havlin et al., 2014). Decomposition of organic phosphorus by phosphatase enzymes produced by soil microorganisms releases inorganic phosphorus that can be absorbed by plants. Besides direct phosphorus contribution from compost, increased organic matter also affects phosphorus availability through several indirect mechanisms. Organic acids produced during organic matter decomposition can form complexes with aluminum and iron ions, thereby reducing phosphorus fixation and increasing available phosphorus in soil solution (Mengel & Kirkby, 2001). The increase in phosphorus from 7.71 ppm to 11.53 ppm in the P2 treatment demonstrates that high-dose compost application is effective in enhancing phosphorus availability in soils experiencing nutrient depletion due to intensive cultivation systems.

Future research directions Overall, understanding the dynamics of phosphorus in soil is crucial for optimizing agricultural practices and mitigating environmental risks. By investigating the various forms of phosphorus, factors influencing its release, and measurement techniques, researchers can develop effective fertilizer management strategies to improve crop yields while minimizing negative impacts on the ecosystem. This knowledge will be essential for ensuring the long-term sustainability of agricultural systems and preserving soil health for future generations. In addition, future research could focus on developing innovative technologies for phosphorus recycling and recovery from agricultural waste streams to reduce reliance on finite phosphate reserves . Studies could also explore the potential of using phosphorus-solubilizing microorganisms to enhance nutrient availability in soil, reducing the need for synthetic fertilizers. By furthering our understanding of phosphorus dynamics, researchers can contribute to the development of more sustainable and environmentally friendly agricultural practices.

Exchangeable Potassium Increase

The increase in exchangeable potassium in compost treatments reflects potassium contribution from organic matter as well as the influence of organic matter on soil cation exchange capacity. Potassium in compost exists in ionic form that is easily released into soil solution and can occupy exchange sites on the soil adsorption complex (Brady & Weil, 2017). Increased soil organic matter enhances cation exchange capacity through addition of negative charges from carboxyl and phenolate functional groups in humic compounds.

The increase in exchangeable potassium from 0.13 cmol kg^{-1} to 0.29 cmol kg^{-1} in the P2 treatment demonstrates that high-dose compost application is effective in increasing readily available potassium reserves for plants. Potassium plays important roles in various plant

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physiological processes, including osmotic regulation, enzyme activation, and assimilate transport (Mengel & Kirkby, 2001). In vegetable cultivation systems requiring high potassium supply for optimal vegetative growth, increasing exchangeable potassium through compost application becomes an effective and sustainable nutrient management strategy.

Based on the data collected and analyzed, it is evident that there is a significant increase in exchangeable potassium levels in various soil types. This increase could have several implications for agricultural practices, including potential impacts on soil fertility and crop production. Further research is needed to fully understand the reasons behind this increase and how it may affect plant health in the long term. In conclusion, the findings of this study highlight the importance of monitoring and managing exchangeable potassium levels in soil for sustainable agriculture practices (Pankaj & Jyoti, n.d. 2016). By understanding the factors contributing to the rise in exchangeable potassium levels, farmers can make informed decisions about fertilizer use and soil management. This knowledge will be crucial in maintaining soil health and optimizing crop yields in the face of changing environmental conditions. Overall, this research underscores the necessity of ongoing monitoring and adaptation in agricultural practices to ensure long-term sustainability and productivity.

Implications for Intensive Horticultural Systems

The results of this study confirm that application of 30 ton ha^{-1} compost is the most effective treatment for restoring physical and chemical soil quality in vegetable land experiencing degradation due to intensive cultivation. Simultaneous improvement in Bulk Density, nitrogen, phosphorus, and potassium demonstrates that compost functions as a comprehensive soil amendment, not only providing nutrients but also improving the physical environment for root growth and soil biological activity.

In the context of horticultural system sustainability, compost-based amelioration strategies offer several comparative advantages over inorganic inputs. Gradual nutrient release from organic matter reduces the risk of nutrient loss through leaching and volatilization, increases nutrient use efficiency, and reduces environmental impacts from excessive inorganic fertilizer application (Suddick et al., 2013). Long-term soil structure improvement through organic matter accumulation also contributes to production system resilience against abiotic stresses such as drought and erosion.

CONCLUSION

Compost application significantly affected the improvement of soil physical and chemical

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properties in vegetable land. Bulk density decreased significantly from 1.44 g cm^{-3} in the control to 1.28 g cm^{-3} in the 30 ton ha^{-1} compost treatment, indicating improvement in soil structure and porosity. Total nitrogen increased from 0.15% to 0.21%, available phosphorus increased very significantly from 7.71 ppm to 11.53 ppm, and exchangeable potassium increased from 0.13 cmol kg^{-1} to 0.29 cmol kg^{-1} at the highest dosage treatment. Based on the research findings, the 30 ton ha^{-1} compost treatment is the most effective dosage for restoring soil quality and can be recommended as an amelioration strategy for sustainable intensive vegetable cultivation systems.

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