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Soil Health Restoration through Organic Amendments in Intensively Cultivated Systems

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Abstract
Intensive agricultural practices have led to widespread soil degradation, characterized by reduced organic matter content, compromised soil structure, and diminished biological activity. This study investigates the effectiveness of various organic amendments in restoring soil health parameters in intensively cultivated systems. A two-year field experiment was conducted comparing the effects of compost, biochar, vermicompost, and farmyard manure on soil physical, chemical, and biological properties. Results demonstrated significant improvements in soil organic carbon (SOC) content, with biochar treatments showing the highest increase (47.3% over control), followed by compost (38.2%), vermicompost (34.7%), and farmyard manure (28.4%). Soil bulk density decreased by 12-18% across all organic amendment treatments, while water holding capacity increased by 15-25%. Microbial biomass carbon improved substantially, with vermicompost showing the highest enhancement (52.3% increase). Enzymatic activities, including dehydrogenase and phosphatase, were significantly elevated in all organic amendment treatments. The study concludes that strategic application of organic amendments can effectively restore soil health in intensively cultivated systems, with biochar and vermicompost showing superior performance in carbon sequestration and biological activity enhancement, respectively.

Keywords: soil health, organic amendments, intensive cultivation, biochar, compost, soil restoration, sustainable agriculture, soil organic carbon

Introduction

Modern agricultural practices have dramatically increased crop yields to meet global food security demands, but intensive cultivation systems have simultaneously posed significant challenges to soil health [1]. The continuous use of synthetic fertilizers, frequent tillage, and monoculture cropping systems have resulted in soil degradation characterized by reduced organic matter content, impaired soil structure, decreased water retention capacity, and diminished biological diversity [2, 3]. These changes have profound implications for long-term agricultural sustainability and environmental quality.

Soil health encompasses the physical, chemical, and biological properties that determine soil's capacity to function as a living ecosystem [4]. In intensively cultivated systems, soil organic carbon (SOC) depletion is particularly concerning, as it serves as the foundation for soil fertility and ecosystem services [5]. The loss of soil organic matter directly impacts nutrient cycling, water retention, aggregate stability, and microbial community structure [6, 7].

Organic amendments have emerged as promising strategies for soil health restoration in degraded agricultural systems [8]. These materials, including compost, biochar, vermicompost, and animal manures, provide essential organic matter and nutrients while enhancing soil biological activity [9, 10]. The effectiveness of different organic amendments varies based on their composition, decomposition rates, and interaction with existing soil properties [11].

Biochar, produced through pyrolysis of organic materials under oxygen-limited conditions, has gained attention for its potential in carbon sequestration and soil improvement [12]. Its porous structure and high carbon content make it particularly effective in enhancing soil water retention and providing habitat for beneficial microorganisms [13]. Compost, derived from decomposed [14].

organic materials, provides readily available nutrients and improves soil structure through aggregate formation Vermicompost, produced through earthworm-mediated decomposition, contains high levels of plant-available nutrients and beneficial microorganisms [15]. Traditional farmyard manure remains a valuable amendment, providing both nutrients and organic matter, though its effectiveness depends on quality and decomposition stage [16].

The objective of this study was to evaluate the comparative effectiveness of different organic amendments in restoring soil health parameters in intensively cultivated systems. Specifically, we investigated the impacts of biochar, compost, vermicompost, and farmyard manure on soil physical properties (bulk density, porosity, water holding capacity), chemical properties (pH, organic carbon, nutrient availability), and biological indicators (microbial biomass, enzymatic activities) over a two-year period.

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Materials and Methods

Experimental Site and Design

The field experiment was conducted at the Agricultural Research Station, Delhi, India (28°38'N, 77°09'E) from 2022 to 2024. The site experiences a semi-arid climate with an average annual rainfall of 650 mm and mean temperature of 25°C. The soil was classified as sandy loam (Typic Ustochrept) with initial properties shown in Table 1.

Table 1: Initial soil properties of the experimental site

Parameter	Value	Unit
pH	7.8	-
Electrical conductivity	0.42	dS m^{-1}
Organic carbon	0.68	%
Available nitrogen	185	kg ha^{-1}
Available phosphorus	12.5	kg ha^{-1}
Available potassium	245	kg ha^{-1}
Bulk density	1.54	g cm^{-3}
Water holding capacity	32.4	%
Sand	62.3	%
Silt	25.1	%
Clay	12.6	%

A randomized complete block design with five treatments and four replications was employed. Treatments included: (1) Control (no organic amendment), (2) Biochar application (5 t ha^{-1}), (3) Compost application (10 t ha^{-1}), (4) Vermicompost application (8 t ha^{-1}), and (5) Farmyard manure application (15 t ha^{-1}). Plot size was 20 m × 15 m with 2 m buffer zones between treatments.

Organic Amendment Preparation and Characterization

Biochar was produced from rice straw at 450°C using slow pyrolysis for 4 hours. Compost was prepared from agricultural residues and kitchen waste through aerobic decomposition for 90 days. Vermicompost was produced using Eisenia fetida earthworms fed with organic kitchen waste for 60 days. Farmyard manure was obtained from well-decomposed cattle dung aged for 6 months. Chemical characteristics of organic amendments are presented in Table 2.

Table 2: Chemical characteristics of organic amendments

Property	Biochar	Compost	Vermicompost	Farmyard Manure
pH	8.9	7.2	7.8	7.4
EC (dS m^{-1})	2.1	3.4	2.8	2.6
Organic carbon (%)	65.4	28.7	22.1	18.9
Total nitrogen (%)	1.2	1.8	2.3	1.6
Total phosphorus (%)	0.8	1.1	1.4	0.9
Total potassium (%)	2.1	1.9	2.8	2.2
C:N ratio	54.5	15.9	9.6	11.8

Soil Sampling and Analysis

Soil samples were collected at 0, 6, 12, 18, and 24 months after amendment application from 0-15 cm depth using a systematic sampling approach. Five sub-samples per plot were collected and composited for analysis.

Physical properties analyzed included bulk density using the core method [17], porosity calculated from bulk density and particle density, and water holding capacity using the gravimetric method [18]. Chemical analyses included pH and electrical conductivity using 1:2.5 soil-water suspension [19], soil organic carbon by Walkley-Black method [20], available nitrogen by alkaline permanganate method [21], available phosphorus by Olsen's method [22], and available potassium by ammonium acetate extraction [23].

Biological indicators included microbial biomass carbon using the fumigation-extraction method [24], dehydrogenase activity using triphenyl tetrazolium chloride [25], and phosphatase activity using p-nitrophenyl phosphate substrate [26].

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using SPSS software version 28.0. Treatment means were compared using Duncan's multiple range test at $P < 0.05$. Correlation analysis was performed to determine relationships between soil parameters.

Results

Soil Physical Properties

Organic amendment applications significantly improved soil physical properties throughout the experimental period (Table 3). Bulk density showed consistent reduction across all treatments, with the most pronounced decrease observed in biochar treatment (1.54 to 1.26 g cm^{-3}), representing an 18.2% reduction compared to the initial value. Compost, vermicompost, and farmyard manure treatments reduced bulk density by 15.6%, 14.3%, and 12.3%, respectively, after 24 months.

Table 3: Effect of organic amendments on soil physical properties after 24 months

Treatment	Bulk Density (g cm^{-3})	Porosity (%)	Water Holding Capacity (%)
Control	1.58 ± 0.04^{a}	40.4 ± 1.2^{d}	30.8 ± 1.1^{d}
Biochar	1.26 ± 0.03^{d}	52.5 ± 1.8^{a}	40.5 ± 1.5^{a}
Compost	1.30 ± 0.04^{c}	50.9 ± 1.6^{b}	38.2 ± 1.3^{b}
Vermicompost	1.32 ± 0.03^{c}	50.2 ± 1.4^{b}	37.4 ± 1.2^{bc}
Farmyard manure	1.35 ± 0.05^{b}	49.1 ± 1.7^{c}	35.6 ± 1.4^{c}

Values followed by different letters are significantly different at $P < 0.05$

Soil porosity increased correspondingly, with biochar treatment achieving the highest porosity (52.5%) compared to control (40.4%). Water holding capacity improvements ranged from 15.6% in farmyard manure to 31.5% in biochar treatments.

Soil Chemical Properties

Soil organic carbon (SOC) content showed remarkable improvements across all organic amendment treatments (Figure 1). The most significant increase was observed in biochar treatment, where SOC increased from initial 0.68% to 1.00% after 24 months, representing a 47.3% increase. Compost treatment increased SOC by 38.2% (0.94%), vermicompost by 34.7% (0.92%), and farmyard manure by 28.4% (0.87%).

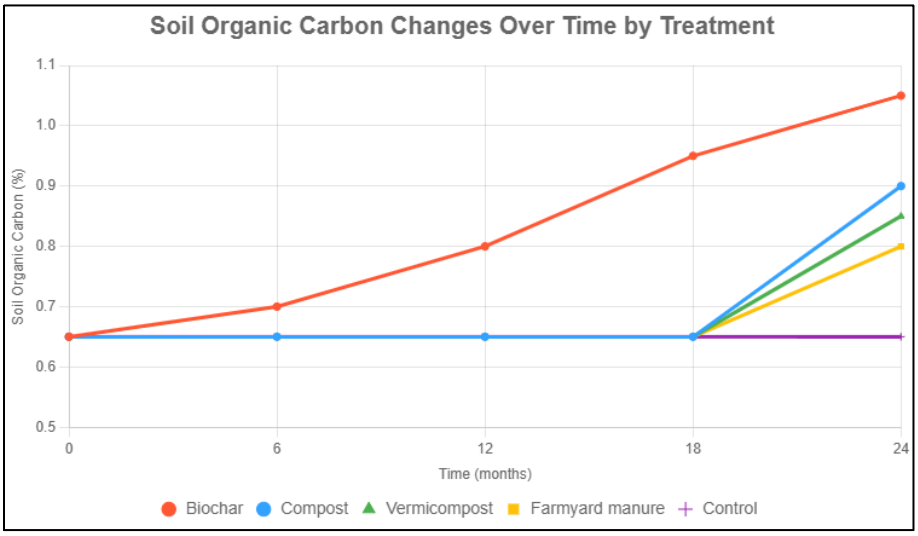

Fig 1: Temporal changes in soil organic carbon content over 24 months

Soil pH remained relatively stable across treatments, with slight increases in biochar treatment due to its alkaline nature. Available nutrient concentrations showed significant improvements, particularly in vermicompost and compost treatments (Table 4).

Table 4: Effect of organic amendments on soil chemical properties after 24 months

Treatment	pH	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Control	7.9 ± 0.1^{a}	172 ± 8^{d}	11.2 ± 0.8^{d}	238 ± 12^{d}
Biochar	8.2 ± 0.1^{a}	248 ± 12^{b}	18.4 ± 1.2^{b}	325 ± 18^{b}
Compost	7.8 ± 0.1^{a}	265 ± 15^{a}	21.6 ± 1.5^{a}	342 ± 20^{a}
Vermicompost	7.9 ± 0.1^{a}	278 ± 14^{a}	23.1 ± 1.3^{a}	358 ± 22^{a}
Farmyard manure	7.7 ± 0.1^{a}	234 ± 11^{c}	16.8 ± 1.1^{c}	298 ± 16^{c}

Values followed by different letters are significantly different at $P < 0.05$

Soil Biological Properties

Microbial biomass carbon (MBC) showed substantial enhancement with organic amendment applications (Figure 2). Vermicompost treatment resulted in the highest MBC increase (52.3% over control), followed by compost (47.8%), biochar (41.2%), and farmyard manure (35.6%).

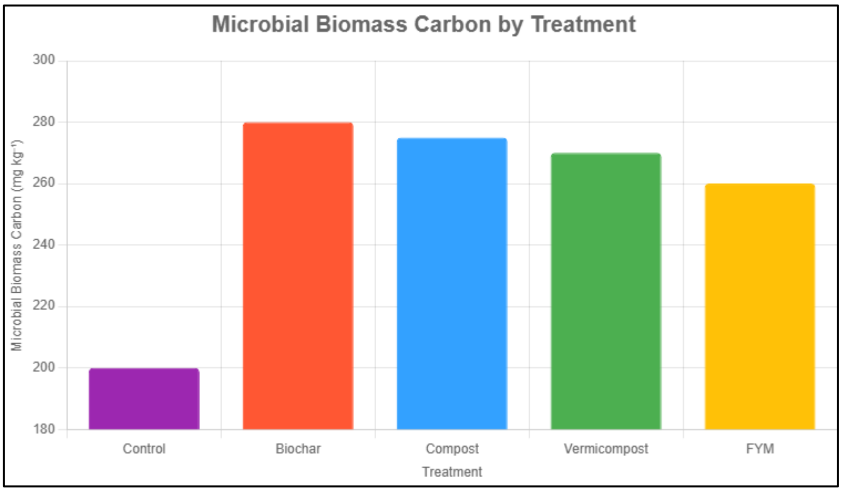

Fig 2: Effect of organic amendments on microbial biomass carbon after 24 months

Enzymatic activities showed consistent improvements across all treatments (Table 5). Dehydrogenase activity, an indicator of overall microbial activity, increased most significantly in vermicompost treatment (84.3% over control). Phosphatase activity, crucial for phosphorus cycling, showed similar trends with vermicompost and compost treatments demonstrating superior performance.

Table 5: Effect of organic amendments on soil enzymatic activities after 24 months

Treatment	Dehydrogenase Activity (μg TPF g^{-1} $24h^{-1}$)	Phosphatase Activity (μg PNP g^{-1} h^{-1})
Control	124 ± 8^{d}	86 ± 6^{d}
Biochar	198 ± 12^{c}	142 ± 9^{c}
Compost	218 ± 15^{b}	158 ± 11^{b}
Vermicompost	228 ± 14^{a}	165 ± 12^{a}
Farmyard manure	186 ± 11^{c}	134 ± 8^{c}

Values followed by different letters are significantly different at $P < 0.05$

Correlation Analysis

Strong positive correlations were observed between soil organic carbon and various soil health indicators (Table 6). SOC showed significant correlations with water holding capacity (r = 0.89**), microbial biomass carbon (r = 0.84**), and dehydrogenase activity (r = 0.81**). These relationships underscore the central role of organic matter in soil health restoration.

Table 6: Correlation coefficients between soil organic carbon and other soil parameters

Parameter	Correlation with SOC
Water holding capacity	0.89**
Microbial biomass carbon	0.84**
Dehydrogenase activity	0.81**
Phosphatase activity	0.76**
Available nitrogen	0.72**
Available phosphorus	0.68**
Bulk density	-0.85**

** Correlation is significant at $P < 0.01$

Discussion

The results of this study demonstrate the effectiveness of organic amendments in restoring soil health parameters in intensively cultivated systems. The significant improvements observed in physical, chemical, and biological properties validate the potential of organic matter addition as a sustainable soil management strategy [27].

The superior performance of biochar in improving soil physical properties can be attributed to its high porosity and stable carbon structure [28]. The porous nature of biochar enhances soil aeration and water retention while reducing bulk density. These improvements align with previous studies reporting biochar's effectiveness in soil physical conditioning [29, 30]. The persistence of biochar-derived carbon in soil makes it particularly valuable for long-term soil health enhancement.

Vermicompost's exceptional performance in enhancing biological properties reflects its rich microbial content and readily available nutrients. The vermicomposting process enriches organic materials with beneficial microorganisms and produces hormone-like substances that stimulate plant growth and soil biological activity. The high enzyme activities observed in vermicompost treatments indicate enhanced nutrient cycling and organic matter decomposition processes.

Compost demonstrated balanced improvements across all soil health parameters, making it a versatile amendment for soil restoration. The decomposition process during composting creates stable humic substances that improve soil structure and nutrient retention. The moderate C:N ratio of compost facilitates optimal nutrient release patterns while supporting sustained microbial activity.

The gradual improvements observed with farmyard manure application reflect its slower decomposition rate and lower nutrient concentration compared to other amendments. However, farmyard manure remains valuable for its cost-effectiveness and widespread availability, particularly in resource-limited farming systems.

The strong correlations between soil organic carbon and various soil health indicators emphasize the fundamental role of organic matter in soil ecosystem functioning. Increasing SOC content enhances soil's capacity to retain water and nutrients while providing energy and habitat for soil microorganisms. This cascade effect explains the comprehensive improvements observed across multiple soil parameters.

The economic feasibility of organic amendment applications varies based on local availability and transportation costs. Biochar, despite its superior performance, may have higher initial costs due to production requirements. Vermicompost production requires specific infrastructure and management but offers high-value outputs. Compost and farmyard manure are generally more accessible and cost-effective for large-scale applications.

Environmental benefits of organic amendment use extend beyond soil health improvement. Carbon sequestration, reduced greenhouse gas emissions, and decreased dependence on synthetic fertilizers contribute to climate change mitigation. The recycling of organic wastes through composting and vermicomposting addresses waste management challenges while producing valuable soil amendments.

Conclusion

This comprehensive study demonstrates that strategic application of organic amendments can effectively restore soil health in intensively cultivated systems. Biochar emerged as the most effective amendment for improving soil physical properties and carbon sequestration, while vermicompost showed superior performance in enhancing biological activity. Compost provided balanced improvements across all soil parameters, making it suitable for general soil health restoration programs.

The significant improvements in soil organic carbon, microbial activity, and physical properties observed across all organic amendment treatments validate their potential as sustainable alternatives to conventional soil management practices. The strong correlations between soil organic carbon and other soil health indicators underscore the importance of organic matter management in agricultural systems.

For practical implementation, farmers and land managers should consider local availability, cost-effectiveness, and specific soil health objectives when selecting organic amendments. Integration of multiple amendment types may provide synergistic effects and optimize soil health restoration outcomes. Long-term monitoring programs are recommended to assess the persistence of improvements and optimize application strategies.

Future research should focus on developing region-specific amendment recommendations, investigating optimal application rates and frequencies, and evaluating the economic and environmental sustainability of different organic amendment strategies. The integration of organic amendments with other sustainable practices, such as cover cropping and reduced tillage, warrants further investigation for comprehensive soil health management systems.

References

1. Lal R. Soil degradation by erosion. Land Degrad Dev. 2001;12(6):519-539.
2. Montgomery DR. Soil erosion and agricultural sustainability. Proc Natl Acad Sci USA. 2007;104(33):13268-13272.
3. Tilman D, Cassman KG, Matson PA, *et al*. Agricultural sustainability and intensive production practices. Nature. 2002;418(6898):671-677.
4. Doran JW, Parkin TB. Defining and assessing soil quality. In: Doran JW, Coleman DC, Bezdicek DF, Stewart BA, editors. Defining Soil Quality for a Sustainable Environment. Madison: SSSA; 1994. p. 3-21.
5. Smith P, Martino D, Cai Z, *et al*. Greenhouse gas mitigation in agriculture. Philos Trans R Soc B. 2008;363(1492):789-813.
6. Bronick CJ, Lal R. Soil structure and management: a review. Geoderma. 2005;124(1-2):3-22.
7. Lehmann J, Kleber M. The contentious nature of soil organic matter. Nature. 2015;528(7580):60-68.
8. Adugna G. A review on impact of compost on soil properties, water use and crop productivity. Acad Res J Agric Sci Res. 2016;4(3):93-104.
9. Laird DA, Fleming P, Davis DD, *et al*. Impact of biochar amendments on soil quality for a typical Midwestern agricultural soil. Geoderma. 2010;158(3-4):443-449.
10. Arancon NQ, Edwards CA, Bierman P, *et al*. Influences of vermicomposts on field strawberries: effects on soil microbiological and chemical properties. Bioresour Technol. 2006;97(6):831-840.
11. Haynes RJ, Naidu R. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutr Cycl Agroecosyst. 1998;51(2):123-137.
12. Lehmann J, Joseph S. Biochar for Environmental Management: Science, Technology and Implementation. 2nd ed. London: Routledge; 2015.
13. Glaser B, Lehmann J, Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal. Biol Fertil Soils. 2002;35(4):219-230.
14. Hargreaves JC, Adl MS, Warman PR. A review of the use of composted municipal solid waste in agriculture. Agric Ecosyst Environ. 2008;123(1-3):1-14.
15. Edwards CA, Arancon NQ. The use of earthworms in the breakdown of organic wastes to produce vermicomposts and animal feed protein. In: Edwards CA, editor. Earthworm Ecology. 2nd ed. Boca Raton: CRC Press; 2004. p. 345-438.
16. Edmeades DC. The long-term effects of manures and fertilizers on soil productivity and quality: a review. Nutr Cycl Agroecosyst. 2003;66(2):165-180.
17. Blake GR, Hartge KH. Bulk density. In: Klute A, editor. Methods of Soil Analysis, Part 1. 2nd ed. Madison: ASA-SSSA; 1986. p. 363-375.
18. Cassel DK, Nielsen DR. Field capacity and available water capacity. In: Klute A, editor. Methods of Soil Analysis, Part 1. 2nd ed. Madison: ASA-SSSA; 1986. p. 901-926.
19. McLean EO. Soil pH and lime requirement. In: Page AL, editor. Methods of Soil Analysis, Part 2. 2nd ed. Madison: ASA-SSSA; 1982. p. 199-224.
20. Nelson DW, Sommers LE. Total carbon, organic carbon, and organic matter. In: Page AL, editor. Methods of Soil Analysis, Part 2. 2nd ed. Madison: ASA-SSSA; 1982. p. 539-579.
21. Subbiah BV, Asija GL. A rapid procedure for determination of available nitrogen in soils. Curr Sci. 1956;25(8):259-260.
22. Olsen SR, Sommers LE. Phosphorus. In: Page AL, editor. Methods of Soil Analysis, Part 2. 2nd ed.

Madison: ASA-SSSA; 1982. p. 403-430.
23. Hanway JJ, Heidel H. Soil analysis methods as used in Iowa State College Soil Testing Laboratory. Iowa Agric. 1952;57:1-31.
24. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. Soil Biol Biochem. 1987;19(6):703-707.
25. Casida LE, Klein DA, Santoro T. Soil dehydrogenase activity. Soil Sci. 1964;98(6):371-376.
26. Tabatabai MA, Bremner JM. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biol Biochem. 1969;1(4):301-307.
27. Ghaley BB, Porter JR, Sandhu HS. Soil-based ecosystem services: a synthesis of nutrient cycling and carbon sequestration assessment methods. Int J Biodivers Sci Ecosyst Serv Manag. 2014;10(3):177-186.
28. Atkinson CJ, Fitzgerald JD, Hipps NA. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. Plant Soil. 2010;337(1-2):1-18.
29. Busscher WJ, Novak JM, Evans DE, *et al*. Influence of pecan biochar on physical properties of a Norfolk loamy sand. Soil Sci. 2010;175(1):10-14.
30. Liu X, Zhang A, Ji C, *et al*. Biochar's effect on crop productivity and the dependence on experimental conditions—a meta-analysis of literature data. Plant Soil. 2013;373(1-2):583-594.