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Role of vermicomposting in organic waste recycling and soil health improvement in farming systems

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Abstract

Vermicomposting transforms low-value organic residues into a biologically rich soil amendment through the digestive activity of earthworms and associated microorganisms. This research evaluated the maturation kinetics of vermicompost produced from mixed agricultural and food waste, then assessed its effects on soil health when applied to wheat and lettuce cropping systems at the Polytechnic University of Madrid experimental farm over two seasons (2021-2022). Vermicompost reached maturity benchmarks (C:N < 15, germination index > 80%) by week 10 of processing. Field application at 5 t ha⁻¹ increased soil organic carbon by 59.4%, microbial biomass carbon by 82.4%, and dehydrogenase activity by 86.0% compared to unfertilized controls. Vermicompost combined with biochar produced the strongest improvements across all soil health indicators. Wheat yield under vermicompost was 18.7% higher than with equivalent-nitrogen farm manure, while lettuce showed 24.3% greater marketable yield.

Keywords: Vermicomposting, organic waste recycling, soil health, microbial biomass, earthworms, biochar, humic acid, dehydrogenase, soil organic carbon, sustainable agriculture

Introduction

Most soil scientists agree on one thing: the biological dimension of soil health has been neglected for too long. As Clive Edwards, the pioneer of vermicomposting research, noted, earthworms are not merely soil inhabitants but active soil engineers that transform organic inputs into forms plants can immediately use ^[1]. Vermicomposting harnesses this capacity in a controlled setting, using epigeic earthworm species to convert organic wastes into a stable, nutrient-rich humus ^[2].

The process differs fundamentally from thermal composting. Where composting relies on thermophilic microbial activity to break down organic matter, vermicomposting operates at mesophilic temperatures through a combination of earthworm gut passage and microbial co-digestion ^[3]. The resulting product contains higher concentrations of plant-available nutrients, humic substances, and beneficial microorganisms than conventional compost ^[4]. Despite these advantages, vermicompost remains underutilized in European farming systems, partly due to limited data on its performance under Mediterranean conditions and its integration with other soil amendments like biochar ^[5].

Climatic and Environmental Conditions

Field trials were conducted at UPM's experimental farm in Madrid (40°27'N, 3°43'W, 650 m altitude) under a continental Mediterranean climate (Csa, Köppen). Mean annual rainfall is 436 mm, concentrated in autumn and spring. Mean temperature is 14.1°C with hot, dry summers exceeding 35°C. Soils are calcareous Calcic Cambisols with loam texture, pH 8.1, and initial SOC of 0.64%. The 2021-2022 research period received 412 and 458 mm rainfall respectively ^[6].

Materials and Methods

Materials

Vermicomposting used *Eisenia fetida* earthworms (density 5 kg m⁻²) in outdoor windrow beds (3 m × 1 m × 0.4 m). Feedstock was a 60:40 mix (w/w) of crop residues (wheat straw, vegetable

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trimmings) and pre-composted food waste from the university canteen. Five soil amendment treatments were compared: T₁—unfertilized control; T₂—farm manure (5 t ha⁻¹); T₃—thermal compost (5 t ha⁻¹); T₄—vermicompost (5 t ha⁻¹); T₅—vermicompost + biochar (4 + 1 t ha⁻¹). Biochar was produced from olive prunings at 500°C.

Methods: Vermicompost maturation was monitored weekly for 12 weeks, measuring C:N ratio, humic acid content (alkali extraction), and germination index (seed bioassay with cress) [7]. Field trials used a randomized complete block design with four replications on 4 m × 3 m plots. Winter wheat (cv. Marius) and spring lettuce (cv. Batavia) were grown in sequence. Soil samples (0-20 cm) were taken at harvest for SOC, available N,

microbial biomass carbon (fumigation-extraction), dehydrogenase activity, and water-stable aggregate analysis [8]. Data were analyzed using ANOVA in R (v.4.2) with Tukey's HSD at $p < 0.05$.

Waste Characterization

Initial feedstock had C:N of 32.4, moisture 68%, and total nitrogen 1.24%. Pre-composting for two weeks before earthworm introduction reduced thermophilic temperatures and eliminated potential phytotoxins. Feedstock heavy metal concentrations were below EU limits for organic farming inputs [9].

Results

Table 1: Crop yield and soil health indicators under five organic amendment treatments after two cropping seasons

Treatment	Wheat (t ha ⁻¹)	Lettuce (t ha ⁻¹)	SOC (%)	MBC (mg kg ⁻¹)	DHA (μg g ⁻¹)	Aggreg. (%)
T ₁ Control	3.21	18.4	0.64	187	28.4	42.1
T ₂ Manure	3.87	22.7	0.78	234	36.7	51.3
T ₃ Compost	4.12	24.8	0.86	267	41.2	58.7
T ₄ Vermicomp.	4.59	24.1	1.02	341	52.8	68.4
T ₅ Vermi+Biochar	4.74	25.3	1.14	387	59.3	74.6
Tukey HSD	0.34	2.1	0.09	38	5.7	6.2

Vermicompost (T₄) outperformed both farm manure and thermal compost for all soil parameters (Table 1). Wheat yield under T₄ was 18.7% higher than farm manure (T₂) and 43.0% higher than

the control. The vermicompost-biochar combination (T₅) produced the highest values across all indicators, with SOC reaching 1.14%—a 78.1% increase over the unfertilized control.

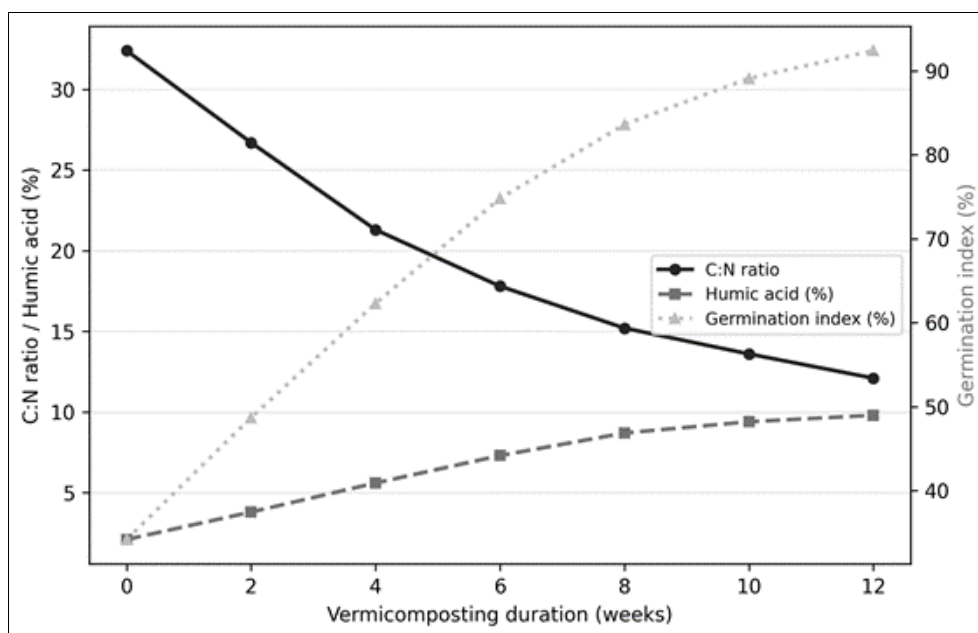


Fig 1: Vermicompost maturation kinetics over 12 weeks showing C:N ratio decline, humic acid accumulation, and germination index increase

The maturation curves (Figure 1) show that C:N ratio dropped below 15 by week 8 and stabilized at 12.1 by week 12. Humic acid content rose from 2.1% to 9.8%, indicating active

humification. The germination index crossed the 80% maturity threshold at week 10, confirming phytotoxin elimination.

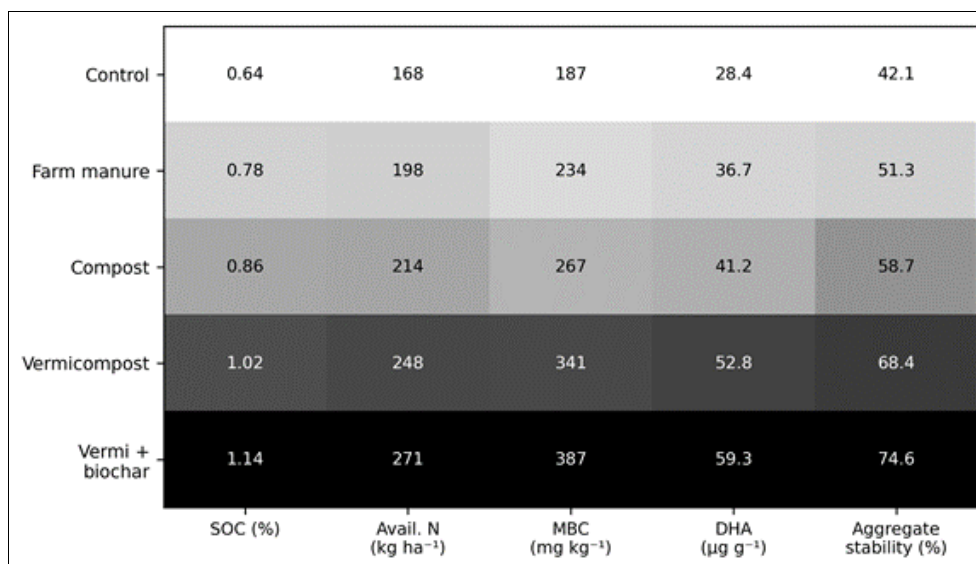


Fig 2: Heatmap of soil health parameters across five organic amendment treatments after two cropping seasons

The heatmap (Figure 2) shows a clear gradient from control (lightest) to vermicompost+biochar (darkest) across all parameters. The vermicompost treatments occupy distinctly darker positions than manure or compost, visually confirming their superior soil-building capacity.

Discussion

The 12-week maturation period for vermicompost is consistent with *Eisenia fetida* processing rates under Mediterranean conditions [10]. The steady decline in C:N ratio reflects progressive mineralization of carbon-rich substrates, while rising humic acid concentrations indicate that earthworm gut passage accelerates humification beyond what microbial decomposition alone achieves [11]. The field results demonstrate that vermicompost's laboratory-measured advantages translate into meaningful agronomic benefits—the 82.4% increase in microbial biomass carbon suggests a fundamental shift in soil biological activity [12].

The synergy between vermicompost and biochar was expected based on their complementary properties: vermicompost provides labile carbon and nutrients that stimulate microbial activity, while biochar offers a porous, stable carbon matrix that retains those nutrients and provides habitat for microorganisms [13]. Under Madrid's calcareous soils, this combination also improved aggregate stability by 77.2% over the control, likely through enhanced fungal hyphal networks binding soil particles [14].

Conclusion

Vermicomposting converted mixed agricultural and food waste into a mature, phytotoxin-free amendment within 10 weeks. Field application at 5 t ha⁻¹ produced greater improvements in soil organic carbon, microbial activity, and crop yield than equivalent rates of farm manure or thermal compost. Combining vermicompost with biochar amplified these benefits further. For Mediterranean farming systems seeking to improve degraded soils while recycling organic wastes, vermicomposting offers a practical, low-cost pathway to enhanced soil health and productivity.

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