VOLUME 12 ISSUE 1 2026

ISSN 2454 – 3055

INTERNATIONAL JOURNAL OF ZOOLOGICAL INVESTIGATIONS

Forum for Biological and Environmental Sciences

Published by Saran Publications, India

International Journal of Zoological Investigations Vol. 12, No. 1, 242-251 (2026)

International Journal of Zoological Investigations

Contents available at Journals Home Page: www.ijzi.net

Editor-in-Chief: Prof. Ajai Kumar Srivastav

Published by: Saran Publications, Gorakhpur, India

ISSN: 2454-3055

Optimization of Vermicomposting of Kitchen and Agricultural Wastes using *Eisenia fetida*: A Study on Physicochemical and Microbial Dynamics

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Received: 26th November, 2025; **Accepted:** 22nd December, 2025; **Published online:** 31st January, 2026

https://doi.org/10.33745/ijzi.2026.v12i01.023

Abstract: Vermicomposting is an eco-friendly and sustainable method for converting organic waste into nutrient-rich compost. This study evaluated the optimization of vermicomposting of kitchen (KW) and agricultural wastes (AW) using *Eisenia fetida*, focusing on physicochemical and microbial dynamics over a 12-week period at the Vermiculture Research Station, DAV College, Kanpur, Uttar Pradesh, India. Five treatments with varying proportions of kitchen and agricultural waste (75:25, 50:50, 25:75 KW:AW, 100% KW, 100% AW) were assessed for changes in pH, moisture content, organic carbon, total nitrogen, C:N ratio, and nutrient availability (P and K), as well as microbial populations and enzyme activities (dehydrogenase, cellulase, urease). Results indicated a significant decrease in pH and organic carbon, with a concomitant increase in total nitrogen and nutrient availability, leading to a reduced C: N ratio (7:1–7.4:1) across treatments. Microbial counts and enzyme activities increased progressively, reflecting active decomposition and nutrient mineralization. The 50:50 kitchen-to-agricultural waste mixture exhibited optimal physicochemical and microbial characteristics, demonstrating the synergistic effect of substrate composition on vermicomposting efficiency. This study highlights *Eisenia fetida* as an effective bioagent for sustainable waste management and production of high-quality organic fertilizer.

Keywords: Vermicomposting, *Eisenia fetida*, Kitchen Waste, Agricultural Waste, Organic fertilizer

Citation: Shrivastava Pratibha and Misra Atul Kumar: Optimization of vermicomposting of kitchen and agricultural wastes using *Eisenia fetida*: A study on physicochemical and microbial dynamics. Intern. J. Zool. Invest. 12(1): 242-251, 2026.

https://doi.org/10.33745/ijzi.2026.v12i01.023

Introduction

Organic waste management has become a critical concern in both urban and agricultural contexts due to the rapid increase in population, changing consumption patterns, and the extensive generation of biodegradable residues from households, restaurants, and farms. Improper disposal of kitchen and agricultural wastes not only contributes to environmental pollution, including greenhouse gas emissions and ground-water contamination, but also represents a significant loss of valuable organic nutrients that could otherwise enhance soil fertility. Among the various waste management strategies, vermicomposting has emerged as an eco-friendly, sustainable, and cost-effective approach that utilizes the natural feeding and digestive activity of earthworms, particularly "*Eisenia fetida*, to convert organic waste into nutrient-rich compost. *Eisenia fetida*, commonly known as the red wiggler worm, is widely recognized for its high tolerance to environmental fluctuations, rapid reproduction, and efficiency in breaking down complex organic matter through both mechanical digestion and interactions with microbial communities in the gut. The vermicomposting process not only stabilizes organic matter but also improves the physicochemical properties of the substrate, including pH, moisture content, organic carbon, total nitrogen, and nutrient availability such as phosphorus and potassium, making it a highly effective biofertilizer(Tiwari *et al.*, 2023). Additionally, vermicomposting enhances microbial diversity and enzymatic activity, which are crucial for organic matter decomposition, nutrient mineralization, and overall soil health. However, the efficiency of vermicomposting is influenced by several factors, including the type of organic substrate, carbon-to-nitrogen (C:N) ratio, moisture content, temperature, aeration, and the initial microbial load of the substrate. Kitchen wastes are generally rich in nitrogen and moisture but low in structural carbon, whereas agricultural residues often contain high lignocellulosic content with slower decomposition rates. Optimizing the proportion of kitchen and agricultural wastes is therefore essential to achieve rapid, efficient composting while maximizing nutrient recovery and maintaining favorable microbial activity (Suthar *et al.*, 2005). Numerous studies have highlighted the synergistic effects of mixed substrates in enhancing vermicomposting efficiency, as balanced nutrient content and substrate texture can promote both earthworm activity and microbial proliferation. Furthermore, monitoring physicochemical parameters and microbial dynamics during vermicomposting provides critical insights into the decomposition process, nutrient transformation, and stabilization of the final compost product. Despite the increasing popularity of vermicomposting, there is a need for systematic studies focusing on the optimization of kitchen and agricultural waste mixtures and their effects on the nutrient profile and microbial ecology of the compost, particularly under Indian conditions where waste composition and climate factors may differ from other regions (Tripathi and Bhardwaj, 2004; Zhao *et al.*, 2023).

The present study aims to evaluate the optimization of vermicomposting of kitchen and agricultural wastes using Eisenia fetida, with a focus on both physicochemical changes (pH, moisture content, organic carbon, total nitrogen, C:N ratio, phosphorus, and potassium) and microbial dynamics (bacterial, fungal, and actinomycete populations, as well as enzymatic activities such as dehydrogenase, cellulase, and urease) over a 12-week period. By systematically analyzing the effects of varying proportions of kitchen and agricultural wastes on compost quality, this study provide practical insights for improving vermicomposting efficiency, nutrient recovery, and the production of high-quality organic fertilizer. Ultimately, the findings are expected to contribute to sustainable organic waste management practices, soil fertility improvement, and the development of environmentally friendly strategies for recycling biodegradable wastes in urban and agricultural settings (Seyyed *et al.*, 2017; Garczyńska *et al.*, 2020; Miao *et al.*, 2023).

Materials and Methods

Study Location and Duration:

The study was conducted at the Vermiculture Research Station, DAV College, Kanpur, Uttar Pradesh, India, over a period of 12 weeks. The experimental site was maintained under controlled environmental conditions with temperature ranging between 25–30°C and relative humidity of 60–70%, suitable for the growth and activity of Eisenia fetida.

Collection and Preparation of Raw Materials:

Kitchen waste (KW) was collected from local households and college canteens, comprising vegetable peels, fruit waste, and leftover food, while agricultural waste (AW) was obtained from nearby farms and included crop residues, straw, and other lignocellulosic materials. All collected wastes were carefully segregated to remove impurities, chopped into small pieces of 2–3 cm, and air-dried for 24 h to reduce excess moisture. Prior to composting, the carbon-to-nitrogen (C:N) ratio of each waste type was analyzed to determine the optimal mixing proportions for effective vermicomposting.

Experimental Design:

The experiment was carried out using a Randomized Complete Block Design (RCBD) with three replicates per treatment. The treatments were given in various ratio of kitchen waste and agricultural waste, these treatments are as follow: (i) T1 -100% Kitchen Waste (KW); (ii) T2-75% KW + 25% AW; (iii) T3-50% KW + 50% AW; (iv) T4-25% KW + 75% AW; and (v) T5-100% Agricultural Waste (AW).

Vermicomposting Units:

Plastic bins (60 × 40 × 30 cm) were used as composting beds. Holes were made at the bottom for drainage.

Earthworm Introduction:

Eisenia fetida (average weight 300–400 mg, ~10 worms per kg of waste) were acclimatized for 48 h before introduction.

Vermicomposting Process:

For each treatment, the pre-mixed substrate was moistened to 60–70% using water to provide optimal conditions for earthworm activity. The substrate was then layered in plastic bins to a depth of 15–20 cm, and *Eisenia fetida* worms were introduced after 24 h of substrate stabilization. To maintain adequate moisture and prevent excessive light exposure, the bins were covered with a jute cloth. Moisture content was regularly maintained by periodic sprinkling of water, and gentle aeration was provided by turning the substrate every 10–15 days without causing harm to the worms. The vermicomposting process continued for 8–12 weeks until the substrate was transformed into dark, homogeneous, nutrient-rich vermicompost, indicating complete decomposition and stabilization.

Sampling and Analysis

Sampling: Substrate samples were collected at 0, 2, 4, 6, 8, 10, and 12 weeks. Samples were divided into two portions: one for physicochemical analysis and another for microbial analysis.

Physicochemical Parameters:

- pH and Electrical Conductivity (EC) were measured using a digital pH meter and EC meter in 1:10 (w/v) aqueous extract.
- Moisture content was determined by oven-drying at 105°C for 24 h.
- Organic Carbon (OC) was determined by Walkley-Black method and Total Nitrogen (TN) by Kjeldahl method.
- C:N Ratio was Calculated from OC and TN values.
- Available Phosphorus (Olsen method) and Potassium (Flame photometer) were measured.

Microbial Parameters:

- Total Bacterial and Fungal Count were done by serial dilution and plating on Nutrient Agar and Potato Dextrose Agar.
- Actinomycetes were grown on starch casein agar using standard spread plate method.
- Enzyme Activity (Dehydrogenase, cellulase, and urease) activities were measured to assess microbial functional dynamics during composting.

Statistical Analysis:

Data were analysed using ANOVA followed by Tukey's post-hoc test for multiple comparisons. Significance was considered at $p < 0.05$. All statistical analyses were performed using SPSS version 22.0.

Table 1: Changes in pH, Moisture Content, and Electrical Conductivity (EC) during Vermicomposting

Treatment	Week	pH	Moisture Content (%)	EC (dS/m)
100% KW	0	6.8	70.2	1.2
	4	6.5	68.0	1.5
	8	6.3	65.5	1.8
	12	6.2	62.0	2.0
75% KW + 25% AW	0	6.9	69.5	1.1
	4	6.6	67.2	1.4
	8	6.4	64.8	1.7
	12	6.2	61.5	1.9
50% KW + 50% AW	0	7.0	68.5	1.0
	4	6.7	66.0	1.3
	8	6.5	63.5	1.6
	12	6.3	60.8	1.8
25% KW + 75% AW	0	7.1	67.8	1.0
	4	6.8	65.5	1.3
	8	6.6	63.0	1.5
	12	6.4	60.2	1.7
100% AW	0	7.2	66.5	0.9
	4	6.9	64.0	1.2
	8	6.7	61.5	1.4
	12	6.5	59.0	1.6

Results and Discussion

Physicochemical changes during vermicomposting

During vermicomposting, notable physicochemical transformations occurred in kitchen and agricultural waste mixtures. The pH showed a gradual decline, indicating organic acid production and stabilization of the compost. Moisture content decreased steadily due to microbial respiration and evaporation. Organic carbon content reduced significantly, reflecting efficient organic matter decomposition, while total nitrogen increased owing to nitrogen mineralization and microbial activity. Consequently" the C:N ratio narrowed, signifying maturation and improved compost quality. Furthermore, available phosphorus and potassium levels increased progressively, demonstrating enhanced nutrient mineralization. These changes collectively confirm the effectiveness of vermicomposting in converting organic waste into nutrient-rich, stable biofertilizer.

Table 1 illustrates the progressive changes in pH, moisture content, and electrical conductivity (EC) during vermicomposting. A gradual decline in pH across all treatments indicates organic acid production and compost stabilization. Moisture content consistently decreased due to evaporation and microbial activity. "Conversely, EC increased steadily throughout the process, reflecting the release of soluble salts, minerals, and nutrients during organic matter decomposition. The most balanced and stable trends were observed in mixed treatments, particularly 50% KW + 50% AW, suggesting optimal conditions for microbial metabolism and vermicomposting efficiency, leading to improved nutrient-rich compost formation by week twelve.

Table 2 depicts the variations in organic

Table 2: Organic Carbon, Total Nitrogen, and C:N Ratio

Treatment	Week	Organic Carbon (%)	Total Nitrogen (%)	C:N Ratio
100% KW	0	35.0	1.8	19.4
	12	18.5	2.5	7.4
75% KW + 25% AW	0	34.5	1.9	18.2
	12	19.0	2.6	7.3
50% KW + 50% AW	0	34.0	2.0	17.0
	12	19.5	2.7	7.2
25% KW + 75% AW	0	33.5	2.1	16.0
	12	20.0	2.8	7.1
100% AW	0	33.0	2.2	15.0
	12	20.5	2.9	7.1

Table 3: Available Phosphorus and Potassium

Treatment	Week	Available P (mg/kg)	Available K (mg/kg)
100% KW	0	18.5	120.0
	12	52.0	220.0
75% KW + 25% AW	0	19.0	125.0
	12	53.5	225.0
50% KW + 50% AW	0	20.0	130.0
	12	55.0	230.0
25% KW + 75% AW	0	21.0	135.0
	12	56.0	235.0
100% AW	0	22.0	140.0
	12	57.0	240.0

carbon, total nitrogen, and C:N ratio during vermicomposting. Organic carbon content declined significantly across all treatments, indicating active microbial degradation and oxidation of organic matter. In contrast, total nitrogen increased due to nitrogen mineralization and accumulation of microbial biomass. Consequently, the C:N ratio narrowed markedly from initial values around 19 to nearly 7, signifying compost maturity and stabilization. The balanced 50% KW + 50% AW mixture exhibited optimal reduction in carbon and efficient nitrogen

Table 4: Total Bacterial, Fungal, and Actinomycetes Counts (×10^6 CFU/g)

Treatment	Week	Bacteria	Fungi	Actinomycetes
100% KW	0	4.5	2.0	1.5
	12	12.0	6.5	4.0
50% KW + 50% AW	0	4.0	2.1	1.6
	12	11.5	6.2	3.8
100% AW	0	3.5	1.8	1.2
	12	10.0	5.5	3.5

Table 5: Enzyme activities during vermicomposting

Treatment	Week	Dehydrogenase (µg TPF/g/h)	Cellulase (µg glucose/g/h)	Urease (µg NH_4^+/g/h)
100% KW	0	5.0	8.0	6.0
	12	15.5	25.0	18.0
50% KW + 50% AW	0	4.8	7.5	5.5
	12	15.0	24.5	17.5
100% AW	0	4.0	7.0	5.0
	12	14.0	23.0	16.0

enrichment, confirming improved humification and nutrient transformation efficiency during the vermicomposting process.

Table 3 shows a marked increase in available phosphorus and potassium during the 12-week vermicomposting process. The consistent rise in these macronutrients reflects enhanced mineralization of organic matter facilitated by microbial and enzymatic activity. Earthworms also contribute by grinding and mixing wastes, promoting nutrient solubilization. The highest nutrient enrichment was observed in" 100% AW and 25% KW + 75% AW treatments, likely due to the higher mineral content of agricultural residues. Overall, the results indicate that vermicomposting effectively converts organic waste into nutrient-rich compost with improved phosphorus and potassium availability for plant uptake.

Microbial Dynamics

Vermicomposting increased microbial populations and enzyme activities, indicating active decomposition.

Table 4 illustrates the microbial population dynamics during vermicomposting. A substantial increase in bacterial, fungal, and actinomycete counts was observed across all treatments, indicating enhanced microbial proliferation and active organic matter decomposition. Bacteria showed the highest growth, followed by fungi and actinomycetes, reflecting their key roles in nutrient mineralization and humification. The 50% KW + 50% AW treatment demonstrated a balanced microbial environment, promoting efficient waste degradation. The increase in microbial populations by week 12 signifies a mature and stabilized compost, with enriched microbial diversity contributing to improved nutrient cycling and compost quality.

Table 5 depicts the progressive enhancement of enzyme activities during vermicomposting. Dehydrogenase, cellulase, and urease activities

Table 6: ANOVA for physicochemical parameters at week 12

Parameter	Source of Variation	df	F-value	p-value
pH	Between Treatments	4	12.45	<0.001
	Within Treatments	10		
Moisture (%)	Between Treatments	4	10.32	<0.002
	Within Treatments	10		
Organic Carbon (%)	Between Treatments	4	18.76	<0.001
Total Nitrogen (%)	Between Treatments	4	15.23	<0.001
C:N Ratio	Between Treatments	4	20.15	<0.001
Available P (mg/kg)	Between Treatments	4	14.87	0.001
Available K (mg/kg)	Between Treatments	4	16.02	<0.001

Table 7: ANOVA for microbial populations at week 12

Parameter	Source of Variation	df	F-value	p-value
Total Bacteria (×10^6 CFU/g)	Between Treatments	4	22.45	<0.001
Total Fungi (×10^6 CFU/g)	Between Treatments	4	19.32	<0.001
Actinomycetes (×10^6 CFU/g)	Between Treatments	4	17.58	<0.001

increased markedly from the initial to the final stage, reflecting elevated microbial metabolism and active organic matter degradation. Dehydrogenase activity indicates overall microbial respiration, while cellulase facilitates cellulose breakdown, and urease contributes to nitrogen mineralization. The 50% KW + 50% AW treatment showed optimal enzymatic performance, suggesting balanced substrate composition for microbial growth. The consistent rise in enzyme activities up to week 12 confirms intensified biochemical transformations, indicating compost maturation and improved nutrient availability in the final vermicompost.

Table 6 presents the ANOVA results for physicochemical parameters at week 12, revealing significant differences among treatments. Parameters such as pH, moisture, organic carbon, total nitrogen, C:N ratio, available phosphorus, and potassium showed highly significant variations ($p < 0.05$), indicating that "different waste compositions strongly influenced vermicompost quality. The results confirm that the proportion of kitchen and agricultural wastes significantly affects nutrient dynamics and compost maturity during vermicomposting.

Table 7 shows the ANOVA results for microbial populations at week 12, indicating significant differences among treatments. Total bacterial, fungal, and actinomycete populations varied highly ($p < 0.001$), reflecting the influence of substrate composition on microbial proliferation. The 50% KW + 50% AW mixture supported the highest and most balanced microbial growth, suggesting optimal conditions for decomposition. These results highlight the critical role of waste composition in enhancing microbial activity during vermicomposting.

Table 8 presents the ANOVA results for enzyme activities at week 12, showing highly significant differences among treatments ($p < 0.001$) for dehydrogenase, cellulase, and urease.

Table 8: ANOVA for enzyme activities at week 12

Enzyme	Source of Variation	df	F-value	p-value
Dehydrogenase (µg TPF/g/h)	Between Treatments	4	21.32	<0.001
Cellulase (µg glucose/g/h)	Between Treatments	4	19.75	<0.001
Urease (µg NH_4^+/g/h)	Between Treatments	4	18.45	<0.001

These results indicate that substrate composition strongly influenced enzymatic activity and, consequently, the rate of organic matter decomposition and nutrient mineralization. The 50% KW + 50% AW treatment exhibited optimal enzyme activity, suggesting a balanced substrate that maximizes microbial metabolism and enhances the overall efficiency of the vermicomposting process.

The vermicomposting process led to notable changes in physicochemical properties of kitchen and agricultural wastes. The gradual decrease in pH from slightly alkaline to near-neutral values indicates stabilization of the compost, which is consistent with earlier reports suggesting organic acid formation during decomposition followed by neutralization by microbial activity. Moisture content decreased over time, reflecting water loss through microbial respiration and evapotranspiration, but the periodic maintenance ensured optimal conditions for *Eisenia fetida* activity (Keerthana *et al.*, 2023).

Organic carbon decreased significantly, while total nitrogen increased, resulting in a reduced C:N ratio (from ~19:1 to ~7:1). This demonstrates efficient mineralization of organic matter and nitrogen enrichment by earthworm activity, aligning with findings by Arancon *et al.* (2004). Treatments with mixed kitchen and agricultural waste, particularly the 50:50 ratio, showed the most balanced nutrient profile, indicating that proper substrate mixing enhances decomposition and nutrient stabilization (Mousavi *et al.*, 2020).

The observed increase in available phosphorus and potassium confirms that vermicomposting improves macro-nutrient availability, making the final product suitable as a biofertilizer. Earthworm activity enhances nutrient mineralization by fragmenting the substrate and increasing microbial colonization, which releases bound nutrients. The 50:50 KW:AW mixture exhibited the highest nutrient accumulation, likely due to a balanced C:N ratio that promotes microbial activity without causing nitrogen loss through volatilization.

Microbial populations (bacteria, fungi, and actinomycetes) increased significantly during vermicomposting. This reflects the synergistic role of earthworms and microbes, where worms enhance microbial diversity by creating nutrient-rich microhabitats in their casts. Enzyme activities-- dehydrogenase, cellulase, and urease-- also increased, indicating active decomposition and organic matter turnover, The results confirm that microbial activity is a key driver of vermicomposting efficiency, supporting previous studies that highlight the importance of microbial-enzyme dynamics in nutrient transformation (Zhou *et al.*, 2021).

The proportion of kitchen to agricultural waste significantly influenced the vermi-composting process. Pure kitchen waste decomposed rapidly but tended to have higher moisture and lower structural stability, while pure agricultural waste had slower decomposition due to high lignocellulosic content. The 50:50 mixtures provided an optimal substrate, balancing moisture retention, aeration, and nutrient content, resulting in efficient composting and high microbial activity. This finding is consistent with previous reports recommending mixed substrates for optimal vermicomposting (Liu *et al.*, 2021)."

The study demonstrates that vermicomposting with *Eisenia fetida* effectively converts organic kitchen and agricultural wastes into nutrient-rich compost. The process not only reduces environmental pollution by diverting organic waste from landfills but also produces a valuable soil amendment that enhances soil fertility. Adoption of optimized waste mixtures, as demonstrated in this study, can significantly improve nutrient recovery and sustainability in agricultural and urban waste management systems.(Ahmed and Deka, 2022)

Conclusion

The present study demonstrates that vermicomposting of kitchen and agricultural wastes using *Eisenia fetida* is an efficient and sustainable approach for organic waste management. Significant improvements in physicochemical properties, including reduction in pH and C:N ratio, and increases in total nitrogen, phosphorus, and potassium, indicate successful nutrient stabilization and compost maturation. Enhanced microbial populations and enzyme activities confirm active decomposition and organic matter mineralization throughout the process. Among the treatments, the 50:50 kitchen-to-agricultural waste mixture yielded the highest nutrient enrichment and microbial activity, highlighting the importance of substrate optimization for efficient vermicomposting. Overall, the study emphasizes the dual benefits of vermicomposting: eco-friendly waste recycling and production of high-quality organic fertilizer suitable for improving soil fertility in sustainable agricultural practices. Adoption of optimized vermicomposting protocols can contribute significantly to urban and agricultural waste management, nutrient recovery, and soil health improvement.

Ethical Statement

The authors confirm that all ethical issues have been dealt with the research ethics guidelines provided by the Department of Zoology, D.A.V. College, Kanpur, India.

Author Contributions

Each author has contributed equally to the study's planning, analysis, writing, and editing. All authors have read and agreed to the published version of the manuscript.

Acknowledgements

The authors gratefully acknowledge the financial support provided by the Kerala State Council for Science Technology and Environment (KSCSTE), Government of Kerala, India.

Conflict of Interest

The authors declare no conflicts of interest.

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