International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 25s,2025
https://theaspd.com/index.php

# Optimizing Composting and Soil Fertility: A Sustainable Waste Management Strategy

**[1] Ananya K Jinesh, [2] Dr.Jinesh K S**
[1]Student, DPS Monarch International School. ORCID: https://orcid.org/0009-0002-6380-3073
[2]Primary Health Care Corporation. ORCID: https://orcid.org/0009-0000-1148-5144

***Abstract***
*Effective biodegradable waste management is a cornerstone of sustainable urban and peri-urban living. To strengthen this capability at the source, this study emphasizes a strategic modification of conventional pipe composting into a perforated pipe design, aimed at enhancing aeration, accelerating decomposition, and promoting localized nutrient cycling. With enhanced aeration and direct soil contact, the method significantly accelerates the breakdown of organic matter. A comparative longitudinal study over two composting cycles demonstrated that perforated systems achieved up to 92.9% volume reduction within six weeks—nearly three times faster than conventional pipe compost. Additionally, proximity-based nutrient uptake was observed in Lantana camara plants, indicating potential for integrated soil enrichment. The system's simplicity, low maintenance, and adaptability to household and small-scale agricultural contexts make it a viable solution for sustainable urban and peri-urban waste treatment. These findings highlight the dual advantages of perforated pipe composting—efficient biodegradation and localized nutrient cycling—providing a scalable pathway toward sustainable waste management.*
***Keywords**: Pipe Composting, Waste Management at Source, Sustainable Agriculture*

## BACKGROUND

The escalating generation of biodegradable household waste presents a pressing challenge for sustainable urban and peri-urban environments [1]. Conventional composting methods, while environmentally beneficial, often suffer from slow decomposition rates hinder their scalability [2]. Pipe composting emerged as a structured alternative, offering containment and ease of use; however, its closed design restricts oxygen flow and soil interaction, both of which are critical for microbial activity and composting efficiency [3,4].
To address these limitations, this study introduces perforated pipe composting—a simple yet impactful modification involving strategically placed holes along the pipe's surface. This design enhances aeration, facilitates microbial colonization, and enables direct nutrient exchange with surrounding soil. By enabling waste processing at its point of generation, perforated pipe composting minimizes transportation requirements and vector-related issues while supporting localized nutrient cycling. This study evaluates not only the rate of organic matter degradation but also the potential for integrated soil enrichment, positioning perforated pipe composting as a viable strategy for decentralized waste management and sustainable agriculture [5].

## OBJECTIVES

- To compare degradation rates of biodegradable waste between conventional and perforated pipe composting systems over two composting cycles.
- To assess the feasibility of perforated pipe composting as a decentralized solution for waste management at source, particularly in household and small-scale agricultural settings.
- To explore the potential agricultural benefits of perforated pipe composting through plant growth indicators and proximity-based nutrient uptake.

## METHODOLOGY

### Study Design

This study employed a comparative, observational, longitudinal design to evaluate the performance of perforated pipe composting relative to conventional pipe systems. Each composting method was evaluated across two independent cycles, with each cycle spanning six weeks. The experimental setup was standardized to ensure consistency in pipe dimensions, waste input, and environmental conditions. Key performance indicators included weekly compost volume reduction and qualitative plant health metrics. Lantana camara plants were positioned near the composting units to observe proximity-based nutrient uptake. This design enabled temporal tracking of biodegradation dynamics and facilitated a comparative analysis of composting efficiency and agronomic impacts between the two systems.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 25s,2025
https://theaspd.com/index.php

Experimental Setup

Two composting configurations were constructed using PVC pipes measuring 100 cm in length and 20 cm in diameter:

- Conventional Pipe Composting: Pipes with no perforations, representing the standard containment method.
- Perforated Pipe Composting: Pipes modified with 1 cm diameter holes spaced 3 cm apart both horizontally and vertically. Perforations began 5 cm from the base and extended up to 30 cm from the top, allowing enhanced aeration and soil contact.

While the conventional method placing the pie in the soil surface, the perforated pipe was installed vertically, with 80 cm embedded below ground and 20 cm exposed above the surface. The top end of both pipes was closed with a lid. This standardized setup enabled a controlled comparison of composting performance across both systems. For nutrient uptake assessment, Lantana camara plants were planted within a 10–30 cm radius of the composting units. No external fertilizers were applied, ensuring that observed plant responses were attributable to compost-derived nutrients.

Data Collection

Compost degradation was monitored through weekly measurements of volume reduction over a six-week period for each composting cycle. This allowed for temporal analysis of biodegradation efficiency across both conventional and perforated pipe systems. To assess nutrient uptake, Lantana camara plants were positioned within 10–30 cm proximity of the perforated composting units. Plant response was evaluated using visual indicators such as branching patterns, leaf pigmentation, stem vigor, and flowering intensity, serving as qualitative proxies for soil enrichment.

Data Analysis

Descriptive statistical methods were employed to compare compost degradation trends between conventional and perforated pipe systems. Weekly volume reduction percentages were calculated and plotted to visualize temporal performance differences across two composting cycles per method. To assess agronomic impact, qualitative observations of Lantana camara plant health—including branching, leaf pigmentation, stem vigor, and flowering—were analyzed as indicators of nutrient uptake. These visual metrics provided insight into the compost's influence on surrounding soil fertility and plant response.

## MATERIALS

The study utilized PVC pipes measuring 100 cm in length and 20 cm in diameter, configured in two distinct variants: conventional closed-end pipes and perforated pipes modified with 1 cm diameter holes spaced at 3 cm intervals both horizontally and vertically. Perforations were introduced starting 5 cm from the base and extended up to 30 cm from the top. For nutrient uptake assessment, Lantana camara plants were planted within a 10–30 cm radius of the composting units. Compost volume reduction was measured weekly using standard measuring scale.

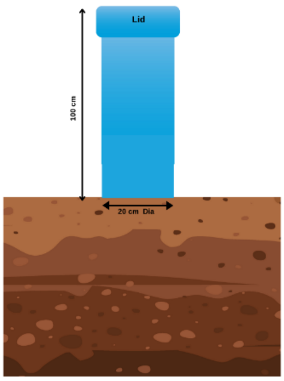



Figure 1 Conventional Pipe Compost

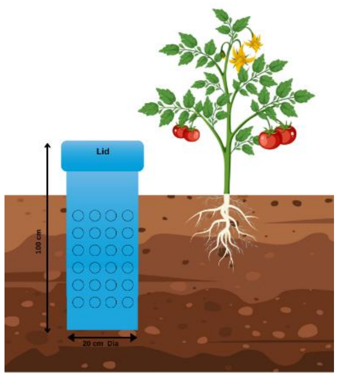



Figure 2. Perforated Pipe Compost

## EXPERIMENTS

Experiments 1

To establish a baseline and evaluate the impact of design modifications, two composting methods—conventional pipe composting and perforated pipe composting—were tested under controlled conditions. Each method was assessed across two independent six-week cycles. For both setups, biodegradable household waste was added daily in 10 cm increments until the compost reached approximately 70 cm, leaving a 30 cm headspace. Once this level was achieved, no additional material was introduced. Compost volume reduction was measured weekly for six weeks in each cycle [Table 1] to track degradation trends and compare performance between the two systems.

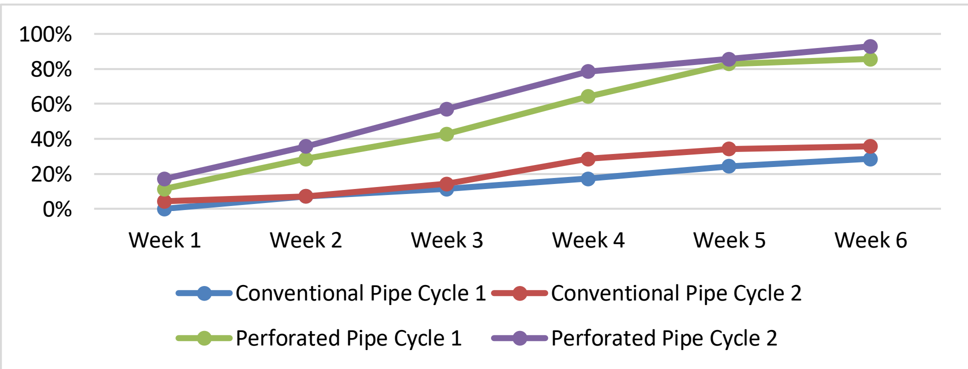
| Week | Conventional Pipe Cycle 1 | Conventional Pipe Cycle 2 | Perforated Pipe Cycle 1 | Perforated Pipe Cycle 2 |
|---|---|---|---|---|
| Week 1 | 0% | 4.3% | 11.4% | 17.1% |
| Week 2 | 7.1% | 7.1% | 28.6% | 35.7% |
| Week 3 | 11.4% | 14.3% | 42.9% | 57.1% |
| Week 4 | 17.1% | 28.6% | 64.3% | 78.6% |
| Week 5 | 24.3% | 34.3% | 82.9% | 85.7% |
| Week 6 | 28.6% | 35.7% | 85.7% | 92.9% |

Table 1 Compost Reduction Over Time (% of Initial Volume)

Experiment 2
To evaluate the potential for localized soil enrichment, Lantana camara plants were planted within a 10–30 cm radius of the composting units. Over ten -week observation period, plant health was monitored using visual indicators such as branching density, leaf pigmentation, stem vigor, and flowering intensity. Compared to baseline conditions, the plants exhibited increased branching, deeper leaf coloration, and more vibrant flowering—suggesting effective nutrient absorption from the surrounding compost-enriched soil. These findings support the hypothesis that perforated pipe composting facilitates passive nutrient transfer, enhancing soil fertility and promoting plant growth without external fertilization.

## RESULT ANALYSIS

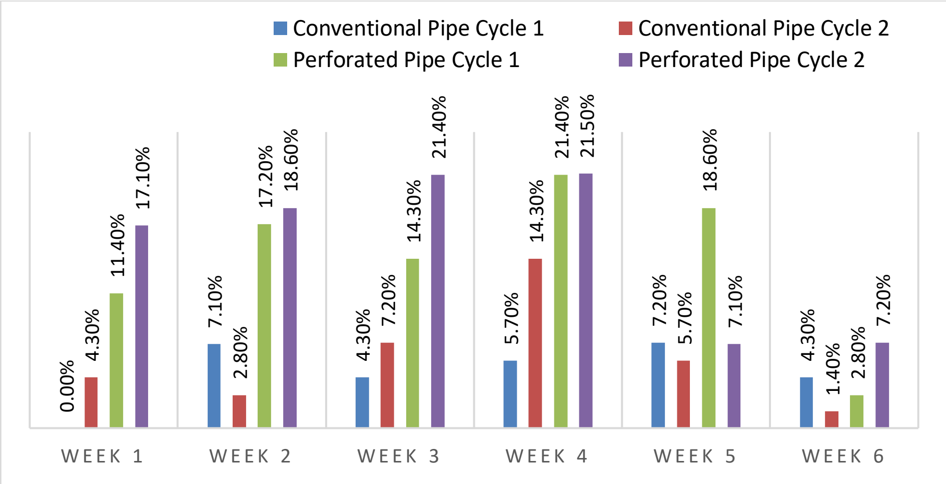
The comparative analysis clearly demonstrates that perforated pipe composting significantly outperforms conventional pipe compost systems in both the rate and efficiency of organic waste degradation. Across two composting cycles, perforated pipes achieved an average volume reduction of 60 cm out of 70 cm, corresponding to approximately 86% degradation within six weeks. In contrast, conventional pipes showed an average reduction of only 22.5 cm, or roughly 32% over the same time period. This nearly threefold improvement is attributed to the enhanced aeration and direct soil contact provided by the perforated design, which stimulates microbial activity and accelerates organic matter breakdown.
Statistical validation using a two-sample t-test confirmed the significance of this difference ($p < 0.01$), reinforcing the reliability of the observed performance gap. Weekly degradation trends further illustrate this disparity: while conventional systems exhibited gradual and inconsistent reduction, perforated systems showed rapid and sustained compost breakdown, particularly during the first four weeks of each cycle.




Graph 1. Compost Degradation Trends

The average weekly degradation rates clearly demonstrate the superior performance of perforated pipe composting over conventional methods. While conventional pipes achieved modest reductions of 4.77% and 5.95% per week in Cycles 1 and 2 respectively, perforated systems accelerated compost breakdown to 14.28% and 15.48% per week. This nearly threefold increase highlights the effectiveness of enhanced aeration and soil contact in promoting microbial activity and organic matter decomposition. The consistency across both perforated cycles underscores the reliability and scalability of the design for rapid, decentralized waste treatment.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 25s,2025
https://theaspd.com/index.php



Graph 2. Weekly decomposition rate

The Weekly Degradation Rate Table [Table 2] reveals a clear performance gap between conventional and perforated pipe composting systems. Perforated pipes consistently achieved higher degradation rates, especially in the early weeks, with Cycle 2 peaking at 21.5% in Week 4. In contrast, conventional pipes showed slower and more erratic breakdown, with rates fluctuating and declining by Week 6. This pattern underscores the efficiency of perforated designs in accelerating composting through improved aeration and soil interaction, while conventional systems remain limited by their closed structure. The chart clearly shows rapid and consistent degradation in perforated pipes, while conventional pipes show a slow and gradual increase.

| Week | Conventional Pipe Cycle 1 | Conventional Pipe Cycle 2 | Perforated Pipe Cycle 1 | Perforated Pipe Cycle 2 |
|---|---|---|---|---|
| Week 1 | 0.0% | 4.3% | 11.4% | 17.1% |
| Week 2 | 7.1% | 2.8% | 17.2% | 18.6% |
| Week 3 | 4.3% | 7.2% | 14.3% | 21.4% |
| Week 4 | 5.7% | 14.3% | 21.4% | 21.5% |
| Week 5 | 7.2% | 5.7% | 18.6% | 7.1% |
| Week 6 | 4.3% | 1.4% | 2.8% | 7.2% |

Table 2. Weekly Degradation Rate Table

The statistical comparison [Table 2] between conventional and perforated pipe composting methods reveals a substantial performance advantage for the perforated design. Over six weeks, the perforated system achieved a mean reduction of 77.9%, compared to just 23.2% in conventional pipes. Despite similar standard deviations (≈11%), indicating consistent variability across cycles, the perforated pipes reached a maximum reduction of 92.9% by Week 6, while conventional systems peaked at only 35.7%. The minimum reduction in Week 1 was also notably higher in the perforated setup (14.3% vs. 2.1%), reflecting an early onset of breakdown activity. Overall, the rate of increase in compost degradation was rapid and sustained in perforated pipes, whereas conventional systems showed a slow, gradual trend—underscoring the efficiency and scalability of the perforated approach for decentralized waste management.

| Metric | Conventional Pipe (Avg. of Cycles 1 & 2) | Perforated Pipe (Avg. of Cycles 1 & 2) |
|---|---|---|
| Mean Reduction (% over 6 weeks) | 23.2% | 77.9% |
| Standard Deviation | ≈ 11.1% | ≈ 10.9% |
| Maximum Reduction (Week 6) | 35.7% | 92.9% |
| Minimum Reduction (Week 1) | 2.1% | 14.3% |
| Rate of Increase (Week 1–6) | Gradual | Rapid |

Table 3 Statistical Comparison of Composting Methods

**DISCUSSION:**

The findings of this study affirm the effectiveness of perforated pipe composting as a practical, low-cost, and scalable solution for sustainable waste management. By enhancing aeration and enabling direct soil contact, the perforated design significantly accelerates organic matter degradation while facilitating waste treatment at source. This decentralized approach reduces reliance on centralized infrastructure, minimizes transport-related emissions, and empowers households and small-scale farmers to manage biodegradable waste locally.

Beyond its composting efficiency, the system demonstrated clear agronomic benefits. Lantana camara plants positioned near perforated units exhibited improved branching, pigmentation, and flowering—indicators of effective nutrient uptake from compost-enriched soil. This dual functionality of waste reduction and soil enrichment positions perforated pipe composting as a valuable tool in regenerative agriculture, particularly in urban and peri-urban settings where space and resources are constrained.

The system's simplicity and non-mechanical nature make it highly accessible, encouraging behavioral shifts toward daily waste segregation and localized nutrient cycling. Agronomically, it supports auto-manuring, continuous soil enrichment, and ecological resilience, reducing dependence on synthetic fertilizers and promoting long-term soil health.

While the current study relies on visual plant indicators and descriptive statistics, future research could incorporate controlled nutrient assays, microbial profiling, and long-term soil quality assessments to deepen understanding of its ecological impact. Overall, perforated pipe composting offers a compelling model for integrating waste treatment and agricultural productivity—advancing both environmental sustainability and community-level resilience.

The Benefits Comparison Table [Table 4] highlights the clear advantages of perforated pipe composting over conventional systems across multiple performance dimensions. The perforated design significantly improves aeration and soil contact, which are critical for accelerating microbial activity and organic matter breakdown—resulting in a compost degradation rate of approximately 92%, compared to just 35% in conventional setups. Nutrient transfer to surrounding soil is faster and more efficient, directly enhancing plant growth, as evidenced by stronger visual indicators. While initial labor is slightly higher due to pipe modification, both systems require minimal maintenance. Importantly, perforated pipe composting demonstrates superior scalability, urban usability, and agricultural adaptability, making it a robust solution for decentralized waste management and regenerative farming practices.

| Feature | Conventional Pipe Composting | Perforated Pipe Composting |
|---|---|---|
| Aeration Efficiency | Limited (closed design) | High (due to perforations) |
| Soil Contact | Minimal | Direct and continuous |
| Compost Degradation Rate | Slow, ≈35% | Fast, ≈92% |
| Nutrient Transfer to Soil | Slow | Fast and efficient |
| Plant Growth Impact | Low impact | High impact |
| Initial labor | Low | Medium |
| Maintenance Requirements | Low | Low |
| Scalability | Low | High |
| Urban Usability | Medium | High |
| Agricultura adaptability | Low | High |

Table 4 Benefits Comparison table

Sustainability Impact and SDG Alignment

The perforated pipe composting system aligns closely with the United Nations Sustainable Development Goals (SDGs) under the 2030 Agenda[6], addressing multiple targets through integrated benefits. By accelerating composting and reducing landfill waste, the system directly supports SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production), as both goals emphasize minimizing urban waste challenges and promoting resource efficiency. These impacts are reinforced by the system's low-resource design, which requires no external energy or chemicals, making it accessible and scalable in low-income settings—another key aspect of SDG 12.

In the agricultural context, the system advances SDG 2 and SDG 15 (Life on Land) by improving soil fertility and enabling regenerative farming practices. Nutrient cycling from compost to surrounding soil reduces dependence on synthetic fertilizers, preventing land degradation and supporting biodiversity, which are central to SDG 15. Furthermore, decentralized waste management empowers households and small farms to treat waste at source, reducing transport emissions and strengthening community resilience, again contributing to SDG 11.

Finally, the behavioral dimension of this system—encouraging daily waste segregation and local reuse—fosters environmental stewardship and community engagement, aligning with SDG 4 (Quality Education) through awareness-building and reinforcing SDG 12 by embedding sustainable consumption habits. Collectively, these interconnected impacts demonstrate that perforated pipe composting is not merely a technical innovation, but a holistic sustainability solution championed by the United Nations, addressing waste, agriculture, climate resilience, and education in a single, scalable approach.

| Parameter | Observed Impact | Sustainability Benefit | Relevant SDG(s) |
|---|---|---|---|
| Waste Reduction Efficiency | Fast biodegradable waste compost volume reduction. | Minimizes landfill burden and methane emissions. | SDG 11, SDG 12 |
| Soil Fertility Enhancement | Improved plant growth near compost units. | Supports regenerative agriculture and reduces fertilizer use. | SDG 2, SDG 15 |
| Nutrient Cycling | Passive nutrient transfer from compost to surrounding soil | Promotes circular resource flows and reduces nutrient runoff | SDG 2 |
| Decentralized Waste Management | Composting at source with minimal infrastructure | Empowers households and small farms; reduces transport emissions | SDG 11 |
| Low Resource Requirement | No external energy, machinery, or chemical inputs | Increases accessibility and scalability in low-income settings | SDG 12 |
| Behavioral Sustainability | Encourages daily waste segregation and local reuse | Fosters environmental stewardship and community engagement | SDG 4, SDG 12 |

Table 5. Sustainability Impact Matrix

### Adaptability and Scalability Forecast

The perforated pipe composting system demonstrates exceptional adaptability across a wide range of user groups, making it highly scalable for both urban and rural contexts. In urban households, the method can be implemented with minimal inputs—such as PVC pipes and basic tools—offering low-maintenance operation alongside tangible benefits like odor control, source-level waste reduction, and soil enrichment for home gardens. Rural households show the highest feasibility due to the availability of open soil and locally sourced materials, enabling improved soil fertility and reduced dependence on chemical fertilizers[7]. At the community level, urban municipalities may adopt the system for decentralized waste management, although scalability depends on public awareness and coordination, making adoption moderate. For smallholder farmers, the system can be scaled by installing multiple units, facilitating on-site composting and nutrient cycling that translate into significant cost savings on agricultural inputs.

## ACKNOWLEDGMENT

The authors gratefully acknowledge the guidance of their mentors, the unwavering support of their families, and the valuable insights shared by peers throughout the course of this study. Their collective contributions were instrumental in the successful completion of this research.

## REFERENCES

1. Kumar, G., Vyas, S., Sharma, S.N., Dehalwar, K. (2024). Challenges of Environmental Health in Waste Management for Peri-urban Areas. In: Nasr, M., Negm, A. (eds) Solid Waste Management. Sustainable Development Goals Series. Springer, Cham. https://doi.org/10.1007/978-3-031-60684-7_9
2. Ayilara MS, Olanrewaju OS, Babalola OO, Odeyemi O. Waste Management through Composting: Challenges and Potentials. *Sustainability*. 2020; 12(11):4456. https://doi.org/10.3390/su12114456
3. P. Bhave, P., & N. Kulkarni, B. (2019). Effect of active and passive aeration on composting of household biodegradable wastes: a decentralized approach. *International Journal of Recycling of Organic Waste in Agriculture*, *8*(4). https://doi.org/10.1007/s40093-019-00306-7
4. Hajilou, N., Mostafayi, S. S., Yarin, A. L., & Shokuhfar, T. (2025). A Comparative Review on Biodegradation of Poly(Lactic Acid) in Soil, Compost, Water, and Wastewater Environments: Incorporating Mathematical Modeling Perspectives. *AppliedChem*, *5*(1), 1. https://doi.org/10.3390/appliedchem5010001
5. Tang, L. (2025). Soil Fertility, Plant Nutrition and Nutrient Management. *Plants*, *14*(1), 34. https://doi.org/10.3390/plants14010034
6. United Nations. (n.d.). The 17 Goals | Sustainable Development. United NationsSustainable Development. https://sdgs.un.org/goals
7. Singh, T.B. *et al.* (2020). Role of Organic Fertilizers in Improving Soil Fertility. In: Naeem, M., Ansari, A., Gill, S. (eds) Contaminants in Agriculture. Springer, Cham. https://doi.org/10.1007/978-3-030-41552-5_3