

DOI: <http://doi.org/10.21698/simi.2025.ab54>

INTENSIVE THERMOPHILIC COMPOSTING FOR SUSTAINABLE MANAGEMENT OF BIODEGRADABLE WASTE IN THE CIRCULAR ECONOMY FRAMEWORK

Elena Elisabeta Manea, Costel Bumbac

National Research and Development Institute for Industrial Ecology-ECOIND, 57-73 Drumul Podu Dambovitei, district 6, 060652, Bucharest, costel.bumbac@incdecoind.ro, Romania

Keywords: *biowaste, circular economy, composting*

Introduction

The management of biodegradable municipal solid waste remains a pressing challenge in the context of rapid urbanization, climate change, and the European Union's circular economy targets. Romania exemplifies the urgency of this issue, with a recycling rate of only 12% and a landfill rate of 74% (Eurostat, 2022), well below EU averages. Traditional waste management approaches have proved insufficient, emphasizing the need for innovative, adaptable, and resource-efficient technologies.

This study explores the potential of intensive thermophilic composting, leveraging residual geothermal energy and optimized feeding strategies, to accelerate organic waste biodegradation, enhance compost quality, and support sustainable nutrient recovery.

Materials and Methods

A modular experimental composting system comprising six thermophilic reactors was designed and operated under controlled laboratory conditions. Feedstocks included restaurant waste (high in proteins, fats, and oils), household kitchen waste (vegetable and fruit residues, cellulose-rich fractions), garden waste (lignocellulosic, high C/N ratio), and mixed blends of the above. A smaller fraction (typically 10–20%) of one category was blended into another. For example, restaurant waste was combined with 10% or 20% garden leaves, or with 10–20% household kitchen residues, in order to study how these proportions influence composting performance and the quality of the final product.

Semi-continuous feeding strategies were tested, with daily loading cycles (0.5–1 kg/unit) and programmed pauses to evaluate system resilience. Key performance indicators included mass reduction, moisture, total organic carbon (TOC), humus fraction, extractable organic substances, and heavy metal concentrations.

Results and discussion

The experimental trials demonstrated that composting reduced the initial waste mass by values ranging from 52% to 82%, depending on feedstock composition and the chosen loading strategies. Organic stabilization was confirmed by the total organic carbon content, which consistently remained within 45–56% dry weight, while the humus fraction reached levels as high as 97%. Compost derived from different waste types showed distinctive nutrient enrichment patterns: potassium was found in

higher concentrations in compost from kitchen waste, while magnesium, iron, and zinc were higher but still within limits in compost obtained from mixed feedstocks, and sodium accumulated predominantly in compost generated from restaurant residues, a consequence of the salt-rich inputs.

The analysis of extractable organic substances revealed that restaurant waste compost yielded the highest concentrations, with values up to 1974 mg/kg dry weight, suggesting improved agronomic value and potential bioavailability. These substances are not newly produced by composting, but rather represent soluble organic compounds that remain available after the degradation process. Their presence indicates that the compost still contains readily accessible nutrients and organic matter fractions, which can be beneficial for plants because they improve bioavailability of nutrients and soil amendment value. Monitoring of heavy metals indicated that Cr(VI) concentrations varied between 3 and 16 $\mu\text{g}/\text{kg}$ dry weight (analysis of Cr(VI) was performed according to SR ISO 11083:1998). Current European and Romanian regulations do not set a specific maximum allowable concentration for Cr(VI) in compost, but instead regulate total chromium. For example, the Romanian technical norm (Order 344/2004 transposing EU standards) establishes a limit of 100 mg/kg dry weight for total Cr in compost. These levels highlighted waste input influence on trace element fluctuations, underlining the importance of continuous process monitoring and feedstock optimization.

Findings confirm the feasibility of semi-continuous intensive composting as a scalable and flexible waste management solution. The process demonstrates robustness even with variable waste streams and loading pauses, suggesting adaptability for decentralized contexts. From a circular economy perspective, the high humus content and differentiated nutrient enrichment underscore the compost's role not only as a waste treatment end-product but also as a value-added soil amendment, supporting both agriculture and soil regeneration.

Conclusions

The validated experimental composting model demonstrates strong potential for scaling towards pilot and industrial applications. Intensive thermophilic composting achieves significant waste reduction while producing high-quality, nutrient-rich compost. Feedstock tailoring allows targeted nutrient recovery, optimizing compost applications in agriculture. Semi-continuous feeding strategies enhance process flexibility and robustness, which is critical for real-world deployment. Moreover, integration with geothermal energy valorization reduces costs and carbon footprint, contributing directly to EU Green Deal targets.

Future work will focus on pilot-scale validation and evaluation of the role of composting in closing urban resource loops.

Acknowledgement

This work was carried out through the "Nucleu" Program within the National Research Development and Innovation Plan 2022-2027 with the support of Romanian Ministry of Research, Innovation and Digitalization, contract no. 3N/2022, Project code PN 23 22 03 02.