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Enhancing the Composting Process of Organic Waste through Machine Learning Techniques: A Comprehensive Bibliometric Analysis

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Abstract

The study explores the integration of machine learning techniques (ML) to improve the composting process of organic waste, amid the growing global challenge of waste management. A decade-long bibliometric analysis (2013-2022) using the Scopus database examined the evolution and impact of ML applications on composting. Their analysis identified important contributions to research and emerging trends, highlighting the fundamental role of ML in optimizing compost production, a critical solution for managing the growing volumes of organic waste generated worldwide. The study revealed how ML models, including artificial neural networks and genetic algorithms, revolutionized composting processes by predicting, improving, and monitoring various composting parameters. In addition, the paper delved into the geographical distribution of research efforts, highlighting the dominance of countries such as China, India and the United States in this area of research. Through the analysis of 180 articles, the study not only mapped out the current picture of ML in composting, but also identified gaps and opportunities for future research. The results defended the potential of the ML to significantly improve the efficiency and effectiveness of composting operations, thus contributing to more sustainable waste management practices. This work is a fundamental resource for both researchers and professionals, with the aim of harnessing the power of the ML in favour of the environment.

Keywords

Machine learning, Composting process, Organic Waste Management, Environmental Sustainability.

1. Introduction

Waste is mainly produced because of human activities and is posing a growing challenge to mitigate the harm they create. An important issue concerns the design of treatment facilities capable of handling the volume and characteristics of municipal garbage (Ragazzi and E.C., 2008).

A study made by the STATISTA website indicated that the United States and China generated 258 and 220.4 million metric tons of Municipal Solid Waste (MSW) respectively, just in 2017 (Statista, 2017) ;this demonstrates the need to generate or design immediate and sustainable solutions over time. In this sense, the correct classification of Urban Solid Waste (USW) plays an important role, however; it is a tedious process, especially in large cities (Behera et al., 2020). Various studies have shown that the content of Urban Solid Waste (USW) differs greatly between countries, regions, or municipalities, encompassing food waste, metals, plastics, glass, textiles, and inert materials, among others (Edjabou et al., 2015).

According to the World Bank's report "*What a Waste 2.0*", the world generates 210 million tons of municipal solid waste, 44% of which is organic waste, 17% paper, 12% plastics, and the remaining percentage split between glass and metal. Rapid urbanization, population growth, and economic development will cause the amount of waste worldwide increases 70% by 2050 (World Bank, 2018). China produced 91.65 million metric tons of domestic trash in 2020, while India and Nigeria created 68.76 and 37.94 million metric tons, respectively. Various solutions, such as composting or anaerobic digestion, have been proposed to prevent and minimize waste creation as organic waste increases with the overall amount of solid waste. The study was conducted by Roy and colleagues in 2018.

Composting is an environmentally friendly and economical alternative for managing organic waste by transforming it into organic fertilizer. (Girón-Rojas et al., 2020). The technique entails the degradation of polymeric waste materials in organic trash by the rapid growth of fungus and bacteria. (Barros et al., 2021). Composting is a multifaceted process involving various interconnected physical, chemical, and biological processes. Connections are frequently nonlinear, necessitating the study of several effects through both experimental and theoretical methods (Soka et al., 2021). Traditionally, these methods have certain defects that are difficult to counter, such as bad odors, degradation time, and the volume they occupy, which is why improvements have been developed, such as co-composting, sewage sludge, aerobic composting, among others. Taking this non-standardized information into account drives research and improvement parameterization in the compost production process using predictive models such as artificial neural networks and genetic algorithms within Machine Learning analysis and artificial intelligence.

This research aims to explore the relationship between Machine Learning studies and advancements in compost-producing companies, with a focus on promoting the recycling of Municipal Solid Waste (MSW) and assessing the potential benefits for new companies considering this strategy. A review of the existing scientific literature will be conducted to develop the necessary bibliometric analysis, which will detail the literature on machine learning techniques for the preparation of compost from organic waste in the period 2013-2022. Considering all that has been described, the following question is established: Is it possible to improve the composting process using solid waste remains by applying machine learning techniques?

1.1 Objectives

Collect and select relevant information from the academic articles reviewed to determine if the composting process using organic waste can be improved through machine learning techniques.

2. Literature Review

Machine Learning is a powerful technology used for processing and analyzing large amounts of data. Researchers have embraced ML to speed up intricate design processes, enhance decision-making, and uncover new insights. (Wang et al., 2022).

Researchers identify temperature, time, moisture content, pH, electrical conductivity, carbon, nitrogen, and the carbon to nitrogen ratio as crucial factors for improving compost quality and maturity. Machine learning is used to develop accurate, dependable, and consistent models of the components of the composting process. The study conducted by Fulya and colleagues in 2023.

Machine learning was originally utilized in 2003 to model aerobic composting of organic waste, primarily to forecast microbial activity during biosolids composting. Recent research has shown that it has a broad range of uses in forecasting, improving, and continuously monitoring MSW composting procedures, leading to a significant rise in the quantity of research papers being produced. (Li-ting et al., 2024).

3. Methods

To guarantee the integrity of the systematic review of this article, the PRISMA method was used, because it provides a useful structure for organizing information and presenting results accurately.

Regarding the search for information, the first step will be to structure the plan for data collection and analysis processing defining the keywords to be used. The second step was to segment and select the articles of greatest relevance to answer the posed question. Finally, the selected articles will be analyzed and reviewed to obtain the results. Next, the detailed steps used for the bibliometric analysis will be shown in Figure 1.

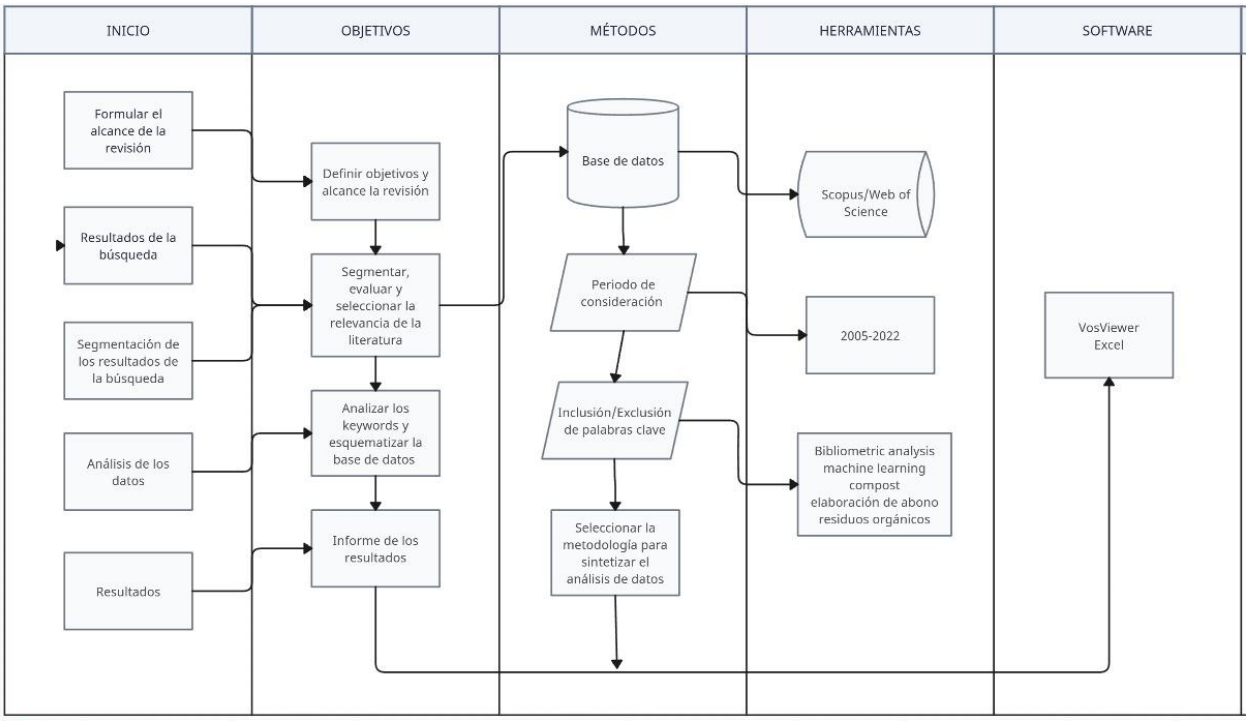

Figure 1. Flow of Information Gathering Process

4. Data Collection

For the data analysis and presentation of results, the bibliometric analysis charts obtained from the Scopus database were interpreted. The search was defined with a delimited period (2013-2022) of articles in English, adding the keywords "machine learning," "composting," "artificial intelligence," and "organic waste" to analyze the research conducted for the acquisition and improvement of compost over the years. In the Scopus database, combinations of keywords were used in the search, detailed in the following Table 1:

Table 1. Advanced Search Criterion

Search Terms	Applied Query	Search Results
"Machine learning" and "organic waste"	Machine learning AND organic waste PUBYEAR >2012 AND <2023 AND (LIMIT TO (PUBSTAGE, "final")) AND (LIMIT TO (LANGUAGE, "english"))	148
“Composting" and “artificial intelligence”	Composting AND learning system AND artificial intelligence” PUBYEAR >2012 AND <2023 AND (LIMIT TO (PUBSTAGE, "final")) AND (LIMIT TO (LANGUAGE, "english"))	32

The analysis was conducted on a total of 180 articles, utilizing the combinations specified in the preceding table. The search includes 764 authors, 3088 keywords, and almost 8500 references. China is the leading country in terms of the number of publications, with 41 publications. Here is a comprehensive list showing the number of research studies conducted by each country:

On the other hand, the authors who made the most significant contributions to the research, according to the number of articles published, were Li, J., Ping, X., Xu, B., Yang, F., Zhang, H., Zhang, W.

5. Results and Discussion

5.1 Bibliometric Analysis

For word match, the tool VosViewer was used to show the relationship they had with the found articles. The main keywords were machine learning, learning systems, artificial intelligence, among others (Figure 2).

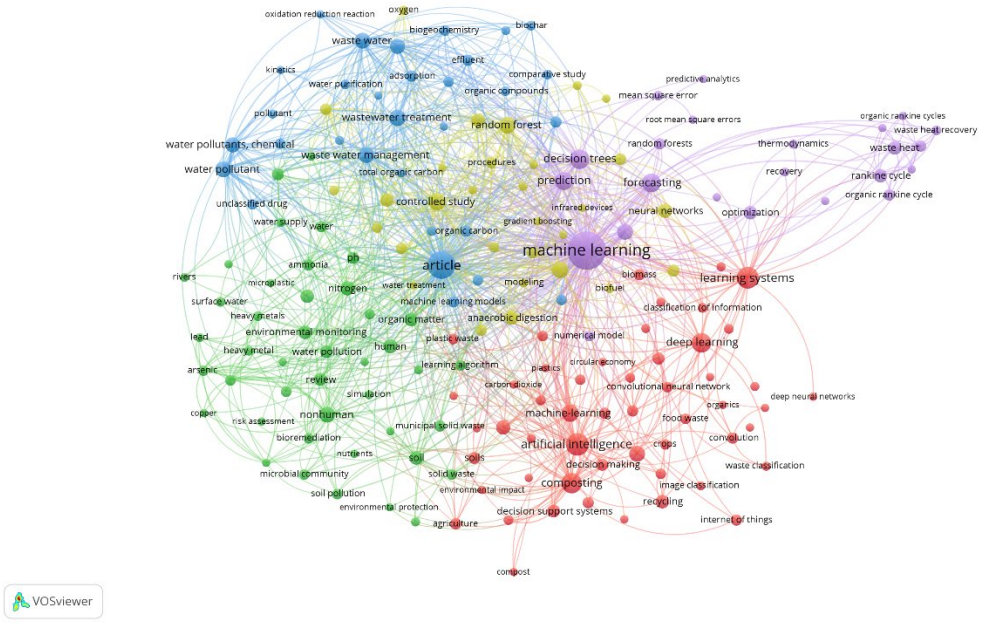

Figure 2. Keywords Concurrency (VOS Viewer)

Composting is the process which is under study for improvement to reduce organic waste, through machine learning with its mathematical models, artificial intelligence, decision trees, neural networks, among others, that is why a direct relationship is established (Figure 3).

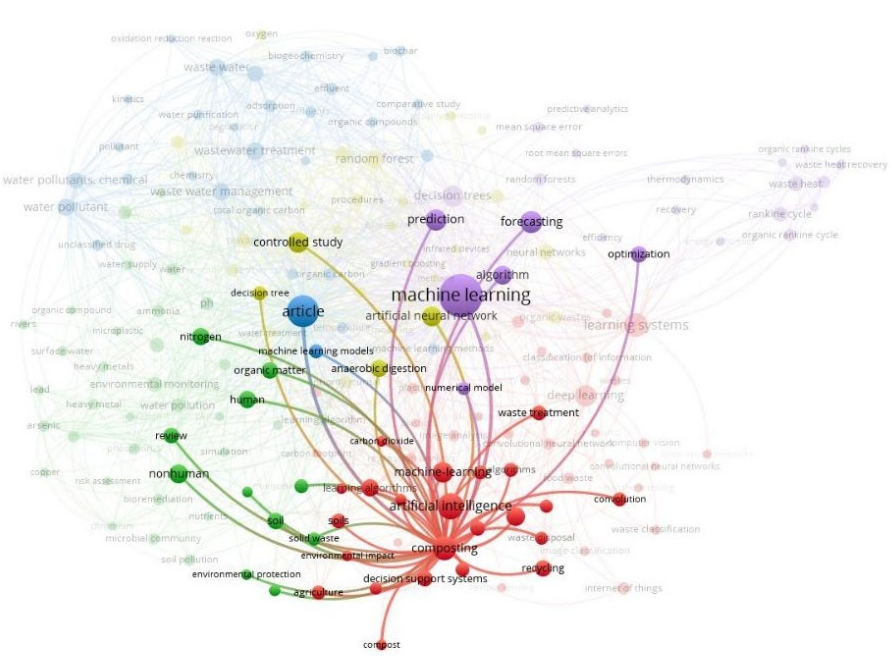

Figure 3. Cluster approach related to composting.

The cluster where the term artificial intelligence is found is related to machine learning, prediction, artificial neural networks, among others. There is a direct relationship between artificial intelligence and machine learning because they are fundamental tools to improve not only composting processes but also in other industries; as is shown in the following Figure 4, research on this subject already exists. In addition, companies which implement artificial intelligence in their processes have a competitive advantage over other companies.

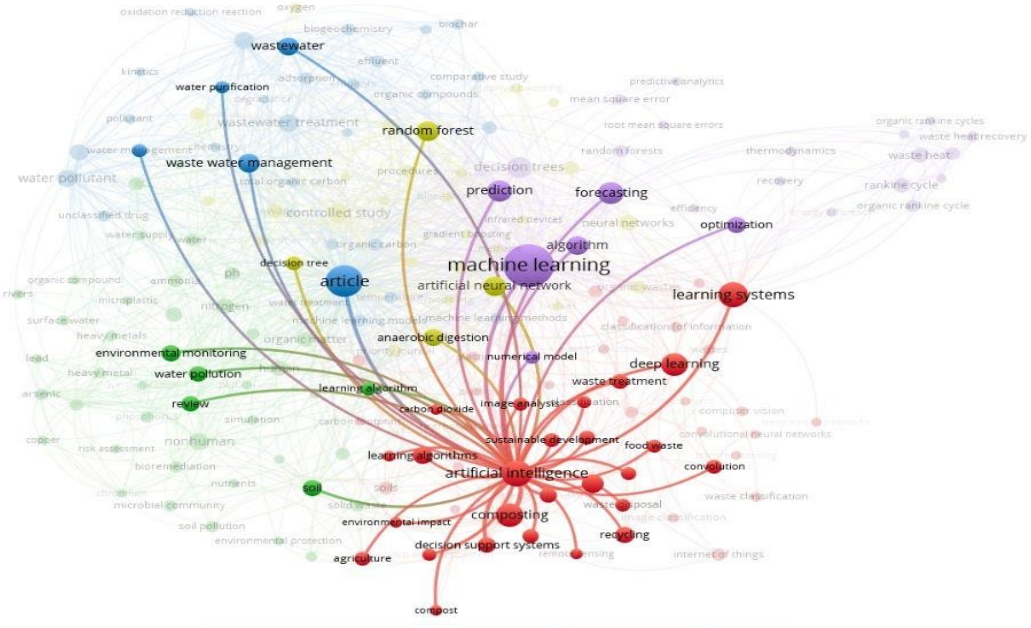

Figure 4. Cluster Approach Related to Artificial Intelligence

The cluster where the term "organic waste" is found is related to machine learning and anaerobic digestion. The co-occurrence of these terms is because machine learning is contributing in the process of disposing of organic waste, through a decomposition process (anaerobic digestion) that produces biogas and also a sub product which is nutrient-rich compost (Figure 5).

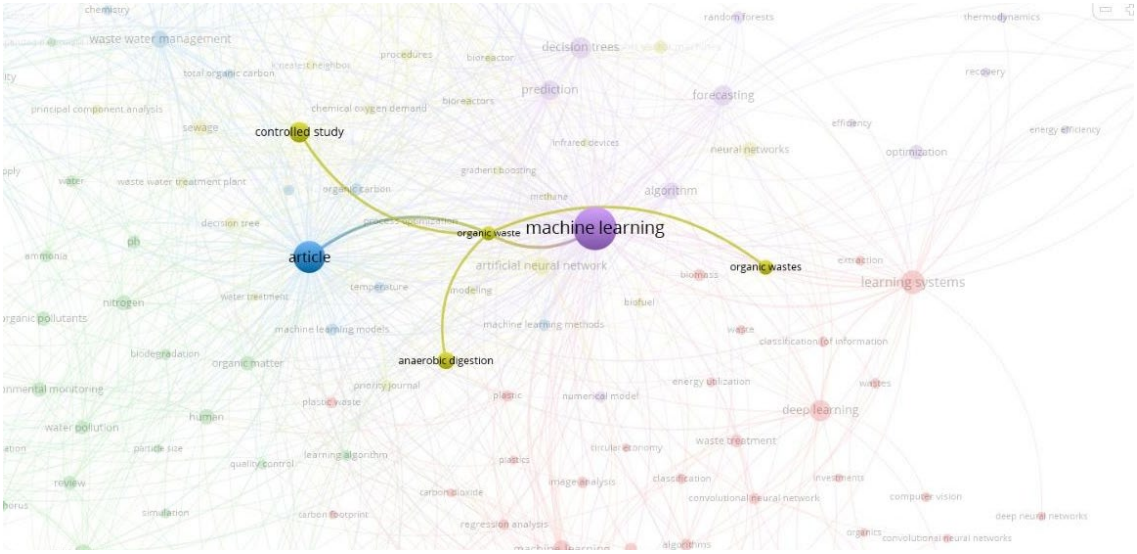

Figure 5. Cluster Approach Related to Organic Waste

As can be observed in the Figure 6, the term "machine learning" is related to different topics such as agriculture, organic, carbon, nitrogen, artificial intelligence, composting, among others. As it was mentioned earlier, the use of machine learning is applied for modeling any process improvement, in this case, composting. In addition, ML allows research with more accurate and certain results.

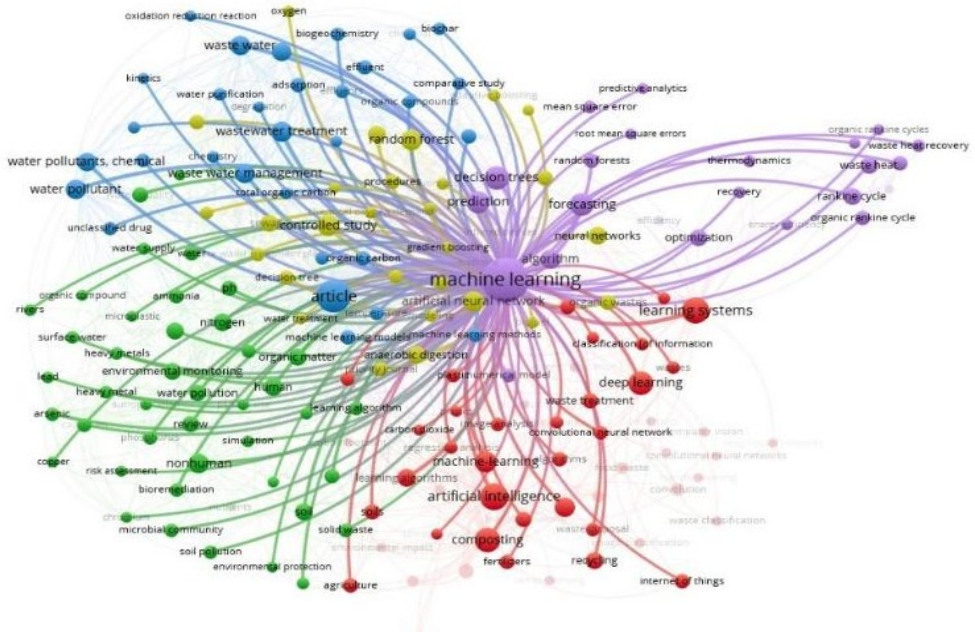

Figure 6. Cluster Approach Related to Machine Learning

5.2 Definition of proposal

After conducting an extensive study about the composting process and machine learning, the relationship between these definitions will be proposed: "ML is being increasingly mentioned and used across all industries to improve different processes. In this case, it will be used to improve the compost production, considering that solid waste is growing exponentially year by year due to population growth, impacting different compost variables such as C/N, pH, moisture, temperature, carbon, nitrogen, and the composting time."

5.3 Contribution of Machine Learning in compost production process

Compost maturity evaluation includes physical indices (temperature, odor, and color), chemical indices (humification, C/N ratio, and nitrate concentration), and biological indices (carbon dioxide (CO2), seed germination index (SGI), etc.) (Li-ting et al., 2024).

Neural networks are a type of learning model in machine learning that are simulated networks that fall under the category of deep learning algorithms. The study by Kujawa et al. (2020) mentioned that evaluating compost maturity using the C/N ratio and SGI is time-consuming, prompting the use of a machine learning technique for faster and direct maturity assessment. Initially, a gray level co-occurrence matrix was created and color blurring was applied to extract texture and color features of the compost components. The Multilayer Perceptron Neural Network (MPL-ANN) was utilized to detect the compost phase. Boniecki et al. (2019) introduced a technique for categorizing compost quality by analyzing color features, employing neural networks and a vector quantization learning algorithm. Neural networks are the primary machine learning technique for forecasting compost maturity through neural image analysis.

ANFIS is a learning model that integrates neural networks and fuzzy logic to efficiently address regression and classification issues across different domains. The framework combines fundamental ideas and characteristics of neural networks and fuzzy logic into a unified system, as outlined by Fulya et al. (2023). ANFIS faces challenges due to its complexity, lack of rule interpretability, and several hyperparameters that need to be determined (Fulya et al., 2023). ANFIS has been used in a limited number of studies to model the parameters of the composting process. Najafi and Ardabili (2018) utilized Multilayer Perceptron (MLP), Adaptive Neuro-Fuzzy Inference System (ANFIS), and logistic regression model to predict biogas production from discarded mushroom compost (SMC) (Najafi et al., 2018).

We provide Support Vector Machines, originally created by Cortés and Vapnik as support vector networks for binary classification purposes. Support Vector Regression (SVR) functions by determining a hyperplane in an N-dimensional space to accurately categorize the data points. The study employed six machine learning models (MLP, RBF, SVR, M5P, M5R, and LR) to predict the bioavailability of 16 polycyclic aromatic hydrocarbons (PAHs) in compost-amended soils. The ML models were evaluated using the Root Mean Square Error (RMSE) metric. The models were graded based on their success on the training sets as follows: RBF > M5P > SVR > MLP > M5R > LR. SVR exhibited the third-highest performance according to the findings (Fulya et al., 2023)..

Finally, we have the Decision Tree (DT), which is based on a binary partition structure in which decisions can be made, represented by a tree in a horizontal shape. This is very similar to a flowchart where each leaf node represents an attribute, and each branch represents a result. Although DT is a machine learning (ML) algorithm, it is not the most recommended for making predictions in the composting process since using incorrect concepts in the data can cause overfitting, time complexity issues, and the partitioning of continuous data shows a tendency towards attributes with multiple variables. The source is from Han and Gu's work published in 2009. Decision Tree (DT) is a data-driven machine learning paradigm where even little alterations in the data can lead to significant variations in the model's outcomes and overall performance. Variables having discrete values are easily separable, but those with continuous values present challenges in partitioning when creating decision trees. Thus, the algorithm may produce an inaccurate classification or regression model. (Fulya et al., 2023)

6. Conclusions

The study concluded that Machine Learning (ML) holds significant promise for enhancing the composting process of organic waste, addressing the urgent need for improved waste management strategies globally. By conducting a comprehensive bibliometric analysis of research from 2013 to 2022, it identified key trends and contributions in the field, emphasizing the transformative potential of ML techniques. The analysis highlighted the role of artificial neural networks and genetic algorithms in optimizing compost production, demonstrating their capacity to predict, improve, and monitor various aspects of the composting process effectively. Moreover, the geographical analysis of research efforts revealed a concentration of work in countries like China, India, and the United States, pointing to a global interest in leveraging ML for environmental sustainability.

The study mapped the current landscape of ML applications in composting, uncovering both gaps and opportunities for future research. It advocated for the integration of ML models to significantly boost the efficiency and effectiveness of composting operations, contributing towards more sustainable waste management practices. The findings serve as a foundational resource for researchers and practitioners, aiming to utilize ML's power for environmental sustainability. The study underscores the importance of advancing ML applications in composting to meet the challenges of increasing organic waste volumes worldwide.

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