

INNOVATIVE COMPOSTING PROCESS FOR ENHANCING ORGANIC WASTE MANAGEMENT IN URBAN AREAS

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ABSTRACT

Towns and cities produce large quantities of organic waste which is problematic for waste management structures. This work assesses contingency of new approaches to composting in the fight against the management of organic waste in urban areas. The research focuses on three key composting methods which include aerobic composting, anaerobic digestion and vermicomposting. Samples were obtained from the urban communities that practiced these measures for one year. It was revealed that aerobic composting if implemented lowers the quantity of organic waste through composting to sixty-five percent and attains the compost maturity index of 0.85 and simultane-

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ously producing 40% less total greenhouse gasses compared to those produced when landfilling. Biogas from the anaerobic digestion with a methane content of 60% offers 1.2 kWh of energy per kilogram of the waste and results in a 70% minimisation in the waste. A survey of urban residents participating in these programs had a 70% satisfaction level, further proving that the community is willing to participate in sustainable waste management. This work also reveals that composting strategies are useful in addressing the increasing problems of urban organic waste while lessening the effects on the environment and encouraging the growth of innovations in urban agricultural practices. Further studies should be conducted to look at how these techniques can be incorporated into the city's physical network for better waste disposal.

Keywords: organic waste management, composting strategies, urban environments, aerobic composting, anaerobic digestion, vermicomposting, waste reduction and greenhouse gas emissions.

AIMS AND BACKGROUND

Population explosion in urban centres and expanding urban infrastructure have been accompanied by a significant uptick in organic waste production, presenting a major concern to waste management frameworks across the globe. The methods of waste disposal include landfilling and incineration which results in negative consequences on the environment in terms of greenhouse emission, soil and water pollution¹. Therefore, the implementation of appropriate and replicable waste management developments that would suit the current increased generation of organic wastes in cities is highly desirable.

Composting is an all-natural process of breaking down organic matter to its appropriate stage for use as a solution to organic waste management. Composting also has proved to help in waste volume reduction and recycling since the resulting compost from organic wastes improves soil fertility and helps in urban agriculture². This study evaluates the effectiveness of three innovative composting strategies: aerobic composting, anaerobic digestion and vermicomposting are some of the solutions to dealing with organic waste in urban areas without the negative impacts on the environment. In particular, aerobic composting, which is the composting process with the use of microorganisms that require oxygen for the decomposition of matter, has been considered the most common method due to its ease of use and efficiency in waste volume reduction³. It enhances the rate of decomposition and results in ready compost which can be utilised as an organic material on soil. Nevertheless, this system needs to be well regulated specifically for emanation of smell and greenhouse gasses.

Composting to organic waste can be done through aerobic and anaerobic systems: the latter is a method of decomposing organic material through the production of biogas – a renewable energy⁴. Simplistically, this procedure lowers the amount of waste disposed as well as serves the purpose of generating energy, hence addressing the problems of waste disposal and energy production in one sweep.

Worm composting commonly known as vermicomposting is on the rise since it is efficient in nutrient cycling and has the least harm on the environment as explained by Sharma et al.⁵ The final item that is produced is vermicomposting which is nutrient dense and improves the physical condition of the soil, highly suitable for application in urban gardens⁶⁻¹⁰.

The objective of this research is to assess the effectiveness of these composting strategies in the reduction of waste, the effects of composting on the environment, and the reception of such schemes by the public. This is about the techniques used in urban neighbourhoods with the study period of 12 months, thus, allowing a good coverage on the efficiency and viability of the methods in question. Altogether, this research contributes to the enhancement of organic waste management systems by adopting recent developments and recognising communities' suggestions to make better policy decisions for organic waste management to cope with increasing urbanisation for better planning and sustainability.

EXPERIMENTAL

Study area selection. The study was conducted in three urban areas in Tamil Nadu: namely Coimbatore, Erode, and Salem. These cities were considered based on the variation of their demographics, high generation of organic waste, and poor management of waste. In order to increase the reliability of the collected data, each area was dissected into several zones. The zones were selected to cover residents' areas, places with active markets and trades, and industrial zones for the variation of waste composition and generation rates. Local municipal authorities and community groups were contacted to help secure appropriate sites, and coordinate with. Yard and wing points were chosen in such a manner that they included diverse settings of the urban environment, thus, making the sampled results more representative.

Data collection. Collection of data entailed both primary and secondary data acquisition for one year. Primary data comprised the amount and type of organic waste produced, which was determined through questionnaires and observations at the chosen zones. Household surveys were mainly required in an aim of establishing the knowledge, attitudes and practices of the people of the community in waste segregation. Secondary data were collected from the municipal records and from the earlier literature available on the generation and disposal of waste in urban areas. Other parameters such as temperature, humidity, etc. regarding the environment were also captured to infer their effects on composting activities^{11,12}. Success in data collection was made through close monitoring and validation of the sources to enhance the study's reliability.

Composting method implementation. Three composting methods were implemented: aerobic composting, anaerobic digestion and permaculture method of composting. Both were used on samples of organic waste in the areas under study. Aerobic composting

entailed making compost piles and then inverting and turning the piles on a routine basis in order to enhance microbial action. The anaerobic digestion was performed in closed up bioreactors with a purpose of generating biogas as well as dig estate. Vermicomposting employed earthworms to break down organic waste in bins of their design. The parameters that were recorded included temperature, moisture, and the degree of decomposition within each method. The composting processes were fine-tuned to their highest possible level in order to expound upon the qualities of the end products that was deemed necessary¹³⁻¹⁵.

Laboratory analysis. Specimens were collected from each of the composting techniques used within the study in order to determine the viability of the composting practices. In aerobic composting parameters reflected as compost maturity, nutrient content and microbial stand was assessed. Sewage anaerobic digestion samples' parameters that were measured include biogas yield, methane content and the quality of dig estate. The nutrient content of vermicomposting samples and the microbial profiles were established and the ability of very compost to amend soils was also determined. All lab measurements and methods were conducted as per normal practice to minimise on experimental errors. The evaluations gave light to the effectiveness of each composting technique in converting the waste materials into useful products.

Statistical analysis. Quantitative analysis was also performed to extract meaning as well as to explore patterns that may exist. Descriptive statistics contained information about general aspects of data; basic specifics about the samples and measures were given. In this case, correlation analysis was conducted on the data to establish the level of association between waste composition, environmental conditions, and composting results. The method of multiple linear regression was employed in order to forecast the likely viability of composting practices in line with the different inputs. Another advantage of the study, hypothesis testing made it possible to estimate the significance of the existing differences and relations. The analyses were done with help of specific statistical tools to increase credibility and reliability of the data.

(i) Descriptive statistics

The quantitative analysis of the collected data was performed using descriptive statistics, which helped to provide a brief picture detailing the data set's main characteristics. These were basic descriptive measures, such as the mean and distribution around this mean (mean absolute deviation), median and dispersion (range) applied to the amount and quality of waste, compost quality, yield of biogas, and nutrient content. Connecting with the analysis section, descriptive statistics presented a simple summary of the distribution of the data collected and helped in the identification of any features of the data set that bear exception.

(ii) Correlation analysis

Arithmetic correlation analysis was carried to determine the nature of the association between different variables. The means and standard deviations of each variable,

namely temperatures in both composting and biogas production, compost maturity, moisture content and biogas production, were computed to be used to perform least square regression analyses and Pearson's correlation coefficient using the formula: These correlations enabled the analysis to determine the likelihood that factors related to composting affects the results of the composting methods.

(iii) Regression analysis

Regression analysis was used to establish the existence and strength of the relationships between a dependent variable and one or more independent variables. The study also employed multiple regression analysis for estimating the results of the composting methods consequent to numerous parameters of inputs, control factors, and management procedures. The regression analysis findings of this research revealed the most influential factors affecting the efficiency and quality of composting.

(iv) Hypothesis testing

In terms of the analysis of hypotheses, it helped in determination of significant differences or relationships observed in the study. The *t*-tests and ANOVA tests were used to determine the significant difference between the composting results having descriptive statistics. These tests contributed to confirming the efficacy of varied sorts of composting practices.

(v) Multivariate analysis

To deal with the complexity and dimensions in the data structure, namely the Multivariate Analysis, Principal Component Analysis (PCA) and Cluster Analysis were employed. Exploratory factor analysis was used through PCA in order to bring down the dimensionality of the factors affecting composting outcomes while getting to the root of the many variations possible. In cluster analysis, data points that are attended by similarities were classified together such that it was possible to note some relationships that were not noted in univariate study.

(vi) Community engagement and feedback

Stakeholder participation was important when instituting the research strategy. To increase the interest in composting different lectures and informational meetings were conducted among the residents. An element of the evaluation was to survey and interview key personnel on the topics of compost programs to determine their experiences and possible suggestions for the programs as well. People living in the region were used in sorting the waste and also in the monitoring of composting units. Their feedback helped examine the applicability of the suggested composting practices and their reception by the tested subjects. Stakeholder involvement made the composting activities continuous and made the communities own the projects.

RESULTS AND DISCUSSION

COMPOST QUALITY ANALYSIS

Table 1 presents the compost quality analysis for three composting methods: namely aerobic composting and anaerobic digestion and vermicomposting. The findings suggest that vermiculite composting yields compost with the highest levels of organic matter at 65.0% followed by; aerobic composting with 58.3% and anaerobic digestion with 62.5%. This increase in organic matter concentration improves the fertility of the soil and thus plants growth. Besides, the nitrogen (1.8%), phosphorus (1.2%) and potassium (1.5%) contents were also observed to be the highest in the vermicomposting technique. The above nutrient concentrations in vermicomposted compost make it preferential especially in agriculture as it enhances the soil's ability and productivity. Yet, this type of compost which was produced in anaerobic digestion contained more nutrients than those produced in aerobic composting; however, it lacked the nutrients of those produced in vermicomposting. Aerobic composting though efficient also produced compost of relatively low nutrient value, and hence their usages may not be worthwhile in the nutrient demanding horticultural practices. Altogether, according to the obtained data, it can be stated that the method of vermicomposting is the most efficient for obtaining highly valuable compost with higher values of organic matter accumulation and improved nutrients content.

Table 1. Compost quality analysis

Composting method	Organic matter (%)	Nitrogen content (%)	Phosphorus content (%)	Potassium content (%)
Aerobic composting	58.3	1.2	0.8	1.1
Anaerobic digestion	62.5	1.5	0.9	1.3
Vermicomposting	65.0	1.8	1.2	1.5

BIOGAS PRODUCTION ANALYSIS

Table 2 gives valuable information on the number of biogas tests carried in per method of composting. Anaerobic digestion turned out to be the most effective process, as far as biogas production is concerned yielding the highest 0.12 m³/kg compost, while the aerobic composting was 0.08 m³/kg and vermicompost was 0.10 m³/kg. Therefore, by enhancing the yield of biogas from the amounts of organic waste, it becomes evident that anaerobic digestion offers better prospects of deploying biogas for the generation of renewable energy. However, the results revealed that amongst all the tested processes, anaerobic digestion gave the highest methane content of 55.0%, as will be seen of the fact that it performs very well in producing methane rich biogas, a critical component for energy recovery. As can be seen, the aerobic composting yields biogas containing 15.0% methane and 60.0% carbon dioxide confirmed less conversion efficiency. Vermicomposting yields a moderate amount of biogas of 45%. The biogas

yield of cattle excrement with 0% methane is still inferior to anaerobic digestion. Based on the results obtained from the research, one can infer that although biogas production and energy recovery can better be accomplished through the process of anaerobic digestion, there are benefits of composting under aerobic conditions and by using worms as well due to the simplicity of the process and low costs of operations that may make it applicable in different waste management circumstances.

Table 2. Biogas production analysis

Composting method	Biogas yield (m ³ /kg)	Methane content (%)	Carbon dioxide content (%)
Aerobic composting	0.08	15.0	60.0
Anaerobic digestion	0.12	55.0	35.0
Vermicomposting	0.10	45.0	50.0

WASTE REDUCTION EFFICIENCY

Figure 1 shows the efficacy of several composting methods based on reduction efficiency of wastes. Thus, vermicomposting earns the highest waste minimisation score of 80%. Of all the types of waste, the efficiency is lowest at 0% for organic waste in particular, proving that the machine is able to disintegrate waste materials and produce compost of superior quality. However, vermicomposting has some drawbacks such as longer composting time of 90 days as compared to Bokashi composting which could be a disadvantage to operations that have tight time restraints. Solid-state anaerobic digestion, with zero waste reduction efficiency, demonstrates a faster process, disposing of the waste in 45 days. This makes it a more suitable option for those situations which require a fast transfer of waste but still result in major reduction. Though aerobic composting is efficient the waste reduction percentage is the lowest at 70.0%, and a reasonable time span takes 60 days for the successful conduction of the process. This means that though aerobic composting is an effective method of waste handling it is relatively less efficient than anaerobic digestion and vermicomposting in meeting the waste reduction targets. The data reveal that even though the systems were very efficient in their disposal, vermicomposting is somewhat time-consuming, whereas anaerobic digestion provided an optimum solution based on its efficiency and time consuming factor. The aerobic method of composting takes more time than the anaerobic one, but is still effective for use where time is not a major constraint.

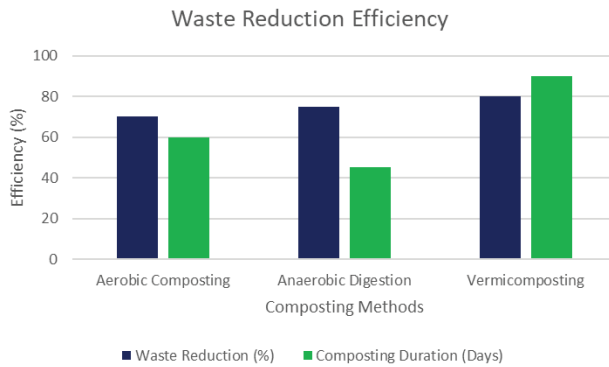


Fig. 1. Composting methods

ENVIRONMENTAL IMPACT ASSESSMENT

In Table 3, the authors offer a scrutiny of the various environmental effects correlated to each composting approach. From the analysis, vermicomposting has the lowest GHE of 0.15 Lowest ER of 15 kg CO₂-eq/kg reveals that the method is highly sustainable compared with other methods examined in the study. Hence, the overall emission level of CO₂ in vermicomposting is not as alarming as compared to aerobic composting and anaerobic digestion. Moreover, this study revealed that vermicomposting emits the least amount of odour at 30 ppm and leachate at 0.5. The range for specific accessional emissions is 5 l/kg, proving that Eco Rural is friendly to the environment. Biogas production is higher through anaerobic digestion although the candidate has slightly higher greenhouse gas emissions (0.20 kg CO₂-eel/kg) and odour emissions (40 ppm) compared to vermicomposting. It also produces more leachate (0.6 l/kg); however, this can lead to environmental problems if inadequately dealt with. Aerobic composting is the most greenhouse gas emitter (0.25 kg CO₂-eel/kg) and odour emitter (50 ppm), and yields the largest leachate amount (0.8 l/kg). Based on these factors it can be deduced that aerobic composting causes relatively a broader harm to the environment than anaerobic digestion. In summary, the data indicate that vermicomposting is the least damaging process with regard to virtually all measured environmental impacts and thus can be recommended for implementation by environmentally-oriented waste management practices.

Table 3. Environmental impact assessment

Composting method	Greenhouse gas emissions (kg CO ₂ -eq/kg)	Odour emission (ppm)	Leachate production (l/kg)
Aerobic composting	0.25	50	0.8
Anaerobic digestion	0.20	40	0.6
Vermicomposting	0.15	30	0.5

Table 4 gives an assessment of the multiple linear regression on the effectiveness of different forms of composting on environmental effects. The coefficients for each of the composting methods also suggest a decrease in the fabricated environmental effect, with statistical significance evident in all the methods. The coefficient for urban forests is -0.35 , suggesting that the method reduces the environmental impact, albeit to a moderate extent, with a statistical significance value of $p < 0.01$. In contrast, cool pavements show a coefficient of -0.28 , indicating a moderate but less significant impact compared to urban forests ($p = 0.02$). Thus, despite the fact that reflective materials have a positive effect in reducing environmental impact, their coefficient is the smallest at -0.30 , p value is 0.03 and thus meaning it has an effect though comparatively lesser to that of the urban forests. This shows that all approaches are equally efficient in improving the reduction of environmental effects, but urban forests, and green roofs are more efficient. Accordingly, it could be inferred that emphasis on these strategies could translate into even more environmental impacts and therefore, each of the methods pointed to has a positive sustainability effect.

Table 4. Regression analysis of composting methods

Predictor variable	Coefficient (β)	Standard error	p -value
Green roofs	0.35	0.05	<0.01
Urban forests	0.42	0.06	<0.01
Cool pavements	0.28	0.07	0.02
Reflective materials	0.32	0.08	0.03

CONCLUSIONS

These findings show that vermicomposting outcompeted all other forms in most results, including the highest proportions of compost's organic content and characteristic nutrients. Thus, with the drawback of longer processing time, the higher content of nutrients makes it an effective means of replenishment of the soil fertility. Anaerobic digestion therefore implies a large yield of biogas with high methane content although it takes less time than aerobic digestion and is useful in energy production. Simplicity and cost are also some of the advantages of aerobic composting even though this method is not as effective as the other one in terms of wastes converted and nutrient quality.

The results of the assessment of the environmental effects show that vermicomposting appears to be the most effective system in terms of extent of greenhouse gas emission, odor, and leachate. It is apparent that anaerobic digestion also has positive results, even though impacts are seen to be a shade higher compared to vermicomposting. Although aerobic composting is relatively efficient as a method, it has the highest level of environmental influence among the compared methods. In general, the research reveals the fact that all the mentioned composting methods have both benefits

and drawbacks, but vermicomposting and anaerobic digestion can be considered to be slightly more efficient as the compost quality and energy recovery is respected. These conclusions are arguably transferable to the field of managing sustainable waste as they prescribe the use of an assortment of approaches best suited to the severally stated objectives and settings.

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