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Aerobic Composting of Organic Waste, Alternative and an Efficient Solid Waste Management Solution

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Abstract: The process of composting which involves the treatment of organic wastes to obtain a stable clean product, has become an increasingly desirable choice, at any scale from home to large waste treatment plants. Composting serves as an alternative to landfilling for managing biodegradable waste while also increasing or preserving soil organic matter, decreasing solid waste, and reducing disposal costs. The compost product improves the condition of the soil, reduces erosion, and helps reduce plant diseases without having adverse impacts on the environment. This study aims to manufacture high-quality compost as a solid waste management method by converting organic waste into a useful resource for the community in a financially and ecologically sustainable manner. We investigated the potential of aerobic composting by controlling the operation process parameters, including monitoring the pH value, temperature, electrical conductivity (EC), carbon-to-nitrogen ratio (C/N), and moisture content during the composting. We studied the physiochemical and biological changes of composting using a 60-liter bioreactor. The composting process determined an average pH value between 6.9 and 7.8, and it revealed a decrease in TOC from 26.18 to 22.19. Additionally, compost process monitoring indicated a maximum temperature rise of 69 °C over the first three days, and then a decrease after 20 days of air temperature. Total nitrogen in the NH_4^+/NO_3^-ratio nitrification decreased to less than 1.4, and the compost in the C/N ratio decreased from 20.75 to 10.035 and setting quality criteria by comparing the final product quality produced through the in-vessel composting.

Key words: Aerobic composting, germination index, agricultural solid waste, C/N ratio.

Introduction

Urbanisation and population growth worldwide lead to significant garbage production, especially in developing nations, causing environmental, social, and economic issues (Awasthi et al., 2014). Population growth and urbanization have accelerated solid waste production, with an estimated 2 billion tons produced globally in 2016 (Solid Waste, 2019). Increased waste production impacts environmental systems, necessitating recycling and reuse in integrated solid waste management systems. Implementing eco-friendly strategies promotes sustainable economic growth globally (Tran, 2021).

Composting, a natural nutrient and soil-beneficial method for managing organic waste, has been studied for thousands of years, focussing on improving quality and reducing processes. Composting has been explored for treating resistant organic pollutants like TPHs and diesel by biodegrading organic compounds (Becarelli, 2019). Organic farm waste, including straw, firewood, and plant leaves, can be recycled into industrial compost, increasing nutrient content and benefiting organic fertilisation, while producing a crumbly, dark brown, and odour-friendly product (Golueke, 1991). Compost enhances soil and crop quality, reduces erosion, and increases drainage, making it a cost-effective,

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accessible, and environmentally friendly alternative to burning waste. Composting efficiently converts solid waste into useful materials, reducing bacteria, diseases, and weed growth by controlling air, moisture, and nutrients (Gonawala et al., 2018). Composting requires oxygen for microorganisms to consume organic waste, generating heat and releasing carbon dioxide and water vapour. Composting stages include Hot Phase, Curing Phase, Cooling Phase II, and Maturation. Compost maturation requires moisture, a C/N ratio, and porosity in the compost mixture (Meena et al., 2021). To meet requirements, mix manure with bulking materials like sawdust, grasses, and straw in a compost mixture above 55°C and no lower than 70°C. Composting is a successful technique for increasing bioremediation of contaminated soil and removing organic waste (Chitsan et al., 2022). Composting and recycling promote environmental sustainability by retaining soil particles and preventing erosion while preserving waste and producing valuable products for soil bioremediation. This research aims to promote ecologically sound waste-efficient management of sustainable compost production and uses in Iraq, contributing to sustainable development by incorporating beneficial organisms. The study examines the impact of physicochemical and biological factors on composting agricultural waste, revealing that bacterial inoculation enhances biomass growth and biological activity.

Materials and Methods

Materials

The study uses agricultural waste, tree leaves, fruit waste, sawdust, and sheep manure to create compost, balancing carbon-to-nitrogen ratios, sourced from Radwaniyah region farms and vegetable markets, (Table 1). The study involved composting using dry and wet tree leaves and twigs, with soil mixed every three days for air, O_2 and water added to adjust water-holding capacity of 50%–60%.

The Cornell Institute for Waste Management's Excel program was used to calculate the actual C:N ratios (AL-Saedi, & Ibrahim, 2019). The C: N ratios of R, M, and B mixture are 25/L, each cell had a total weight of 20.75 kg and to calculate the percentage of C: N used Eqs(1).:

$$G = \frac{M_1Q_1 + M_2Q_2 + M_3Q_3}{Q_1 + Q_2 + Q_3} \quad (1)$$

$$R = \frac{Q_1(C_1 + (100 - M_1)) + Q_2(C_2 \times 100 - M_2) + Q_3(C_3 \times (100 - M_3)) + \ldots}{Q_1(N_1 + (100 - M_1)) + Q_2(N_2 \times 100 - M_2) + Q_3(N_3 \times (100 - M_3)) + \ldots} \quad (2)$$

which
Q_n = mass of material n on a wet weight basis,
Q_n = C/N ratio of the compost mixture.
C_n = the carbon content %, N_n = nitrogen content %,
M_n = moisture content % of material n.

Equation 3 represents the mass of the third material required after simplifying and rearranging the preceding equation.

$$Q_3 = \frac{RQ_1N_1(100 - M_1)) + RQ_2N_2(100 - M_2) - Q_1(C_1 \times (100 - M_1)) + Q_2(C_2 \times (100 - M_2))}{(100 - M_3) - RN_3(100 - M_3)} \quad (3)$$

Additionally, the mature compost was a source of microbes that sped up the composting procedure. Over roughly thirteen weeks, we conducted three experiments on the composting process using the waste materials (Table 2).

Reactor Design

Three rectangular plastic containers with a usable space of 48 cm^2, measuring (44 long × 36.5 broad × 53.5 high) cm, utilised as bioreactors (Figure 1). For aerobic conditions and quick composting, every 3 days

Table 1: Cornell Waste Management Institute (2014)

Ingredient	*% Moisture*	*% Carbon*	*% Nitrogen*	*Mass (lbs)*
Sheep manure	60.00	43.2	2.7	22.00
Leaves, compacted & Moist	38.00	48.6	0.9	1.10
Fruit wastes	62.00	56.0	1.4	22.00
Sawdust	65.00	106.1	0.2	0.55
Calculate mixture moisture content				60.5
Calculate mixture C/N ratio				25.00

Table 2: Ratio & weight of composting material

No.	*Experiment no.*	*Ingredients*	*The weight (Kg)*	*Ratio %*	*Specification*
1	R	SHM: LM: FW: SD	10:0.5:10:0.25	48:2.4:48:1.2	1 kg soil + mixture compost + 0.5 L diesel oil
2	M	SHM: LM: FW: SD	10:0.5:10:0.25	48:2.4:48:1.2	1 kg soil + mixture compost + 1 L diesel oil
3	B	SHM: LM: FW: SD	10:0.5:10:0.25	48:2.4:48:1.2	1 kg soil + mixture compost + 1.5 L diesel oil
4	Control				1 kg soil + 1L diesel oil

move the compost material from container to container for necessary mixing. Additionally, the containers are put at an angle of less than fifteen degrees to extract and recycle leachate. The holes allowed air to enter, oxygen to supply, and gaseous emissions and heat of decomposition to exit. The rectangular container plastics also had removable lids and insulation for heat retention. The experiment lasted over 90 days to produce aerobic conditions and be more successful in energy savings and emission reduction.

Sampling and Analysis

Each container's samples are collected in 200 g plastic vials for testing in the laboratory. While the samples are being tested, certain important research is being performed to determine the quality of the experiments and the period of maturity of materials within systems. Food waste mixed with (C/N) a ratio of 25. Compost samples measuring approximately 250 g were from various points in containers, primarily the top, middle, and end terminals. To produce a homogenized sample, all of the samples were blended. Triplicate homogenized samples were taken (0, 1, 4, 7, 10, 35, 90 days) at 4°C for biological testing of the wet samples within 2 days. Some samples were air-dried and quickly passed through a 0.2 mm sieve before being kept for physicochemical examination. The temperature of the composting container (CCn) is monitored and measured every 6 hrs. As a measurement of the temperature of the composting material, the average value was used. To prevent heat loss, the container covered in the aeration rate was monitored. Each sample was analysed and determined the pH (Manga et al., 2022), Electrical Conductivity (EC), ash, calculated total nitrogen by Kjeldahl Method (NH_4^+-N and NO_3^--N), and (TOC) all examined and quantified in each sample. Potassium, and phosphorus, both total and available.

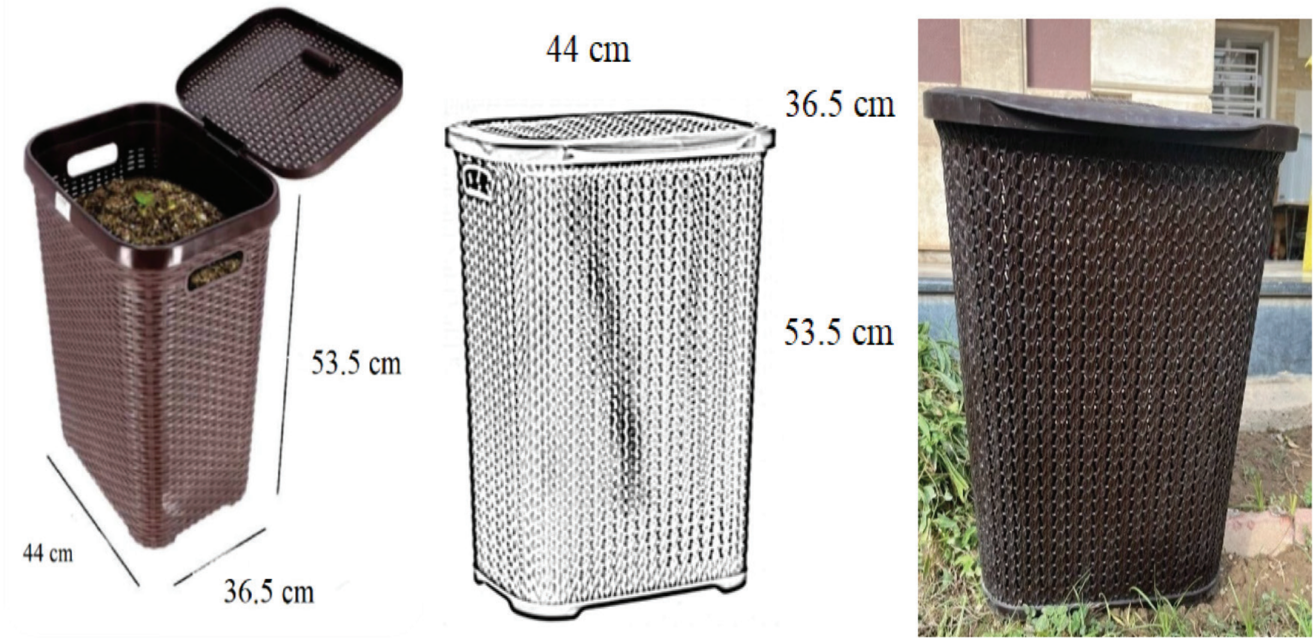


Figure 1: A container shape in the composting process.

Result and Discussion

Characterisation of Composting Material

Particle Size

The initial particle size of composting materials is crucial for two reasons; determining the surface area for microbes and determining the homogeneity of the mixture. Smaller particles have higher surface areas, allowing for efficient breakdown and homogeneous mixing. However, they may restrict air and water penetration, leading to anaerobic zones (ASTM D6913-04 (2009). Larger particle sizes cause increased ventilation, decreased water-holding capacity, and slower deterioration. There is no consensus on the ideal particle size for composting, but various studies have investigated different particle sizes, such as 1 cm in food waste composting and 1.5-2.0 cm in sheep manure composting (Zhao et al., 2017).

Temperature

The composting process was monitored using digital thermometers at various locations, including the starting, center, and end locations. The temperature was recorded in line with the standard mesophilic-thermophilic-maturation range. The container temperature increased from room temperature to above 60°C within 3-15 days due to the appropriate C:N and heat release (Al-Zubaidi, 2013). After three days, containers (R, M, B) transitioned from an initial mesophilic phase (30°C) to a thermophilic phase. The first phases of composting saw temperatures rise due to the biological breakdown of organic components in solid waste or other organic substances. The concentration of stable chemicals in the container increased, making them less available to microbes (Thinakaran et al., 2009). The temperature gradually decreased until it reached a level similar to ambient temperature. The second mesophilic phase occurred from the 8th to the 16th, indicating the maturation process (Figure 2) (Al-Saedi & Ibrahim, 2019).

The pH Value

The pH variation during composting, affects efficiency. Initial pH below 5.5, lowered to 4.3 in early days due to rapid temperature rise, organic mass at room temperature, and mesophilic organisms multiplying. The first stage of composting produces simple organic acids, which decrease the pH due to bacteria breaking down organic materials (TMECC, 2002). Mixes' acidity values drop to neutral, stabilise ten days later, and microbial activity converts these acids into CO_2, restoring pH to neutral. The final day of the trials showed a pH higher than 7, with aeration contributing to the increase in pH during degradation (McKinley and Vestal, 1985). The mature compost's pH was close to neutral (6.5-7.8), indicating high-quality compost within the recommended range of 6–8.5 (Manga et al., 2022). The slight pH drop at the end of the process is attributed to the formation of sodium acetate and acetic acid compounds as buffers, Figure 3.

Electrical Conductivity (EC)

The electrical conductivity (EC) of a composting product can indicate its salinity, which can have potential phytotoxic effects on plant development (Lin, 2008). The initial increase in EC may be due to mineral

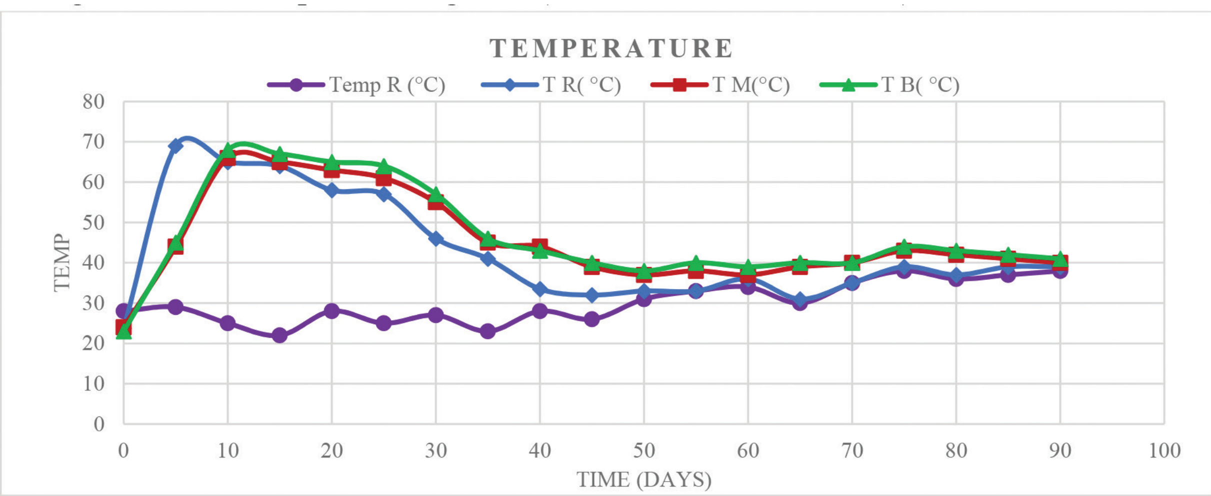


Figure 2: Variations temperature vs time.

salt release during organic decomposition, with no significant changes in EC concentration observed for three containers. Compost with low EC is used directly, while compost with high EC requires thorough mixing with soil or other low EC materials before use (Choi, 1999). The EC for containers R, M, and B increased to 3.32, 5.56, 6.2, and 5.4 ds/m, respectively. Figure 4 depicts of EC change of three heaps, with electrical conductivity values of 3-12 ms/cm showing the maturity of the compost. Similarly reported in water hyacinth and municipal waste composting (Awasthi et al., 2015; Kalamdhad and Kazmi, 2008).

Moisture Content

Moisture significantly impacts composting, influencing microbial activity and physicochemical properties. High moisture levels can prolong incubation periods and encourage harmful germ development (TMECC, 2002). Low moisture content (40%) allows for early drying, influencing nutrient absorption. The ideal moisture content for aerobic composting is between 50 and 60% (Figure 5). The R, M, and B containers used 55-65% initial materials, a common range in composting studies, as mature compost requires less space, lowers transportation costs, and reduces microbiological activity (Tran et al., 2021).

C/N Ratio

Carbon-to-nitrogen (C/N) is a crucial factor in composting, affecting the final compost quality and the composting process (Kumar et al., 2010). The ideal C/N for composting materials is 25-30, ensuring carbon

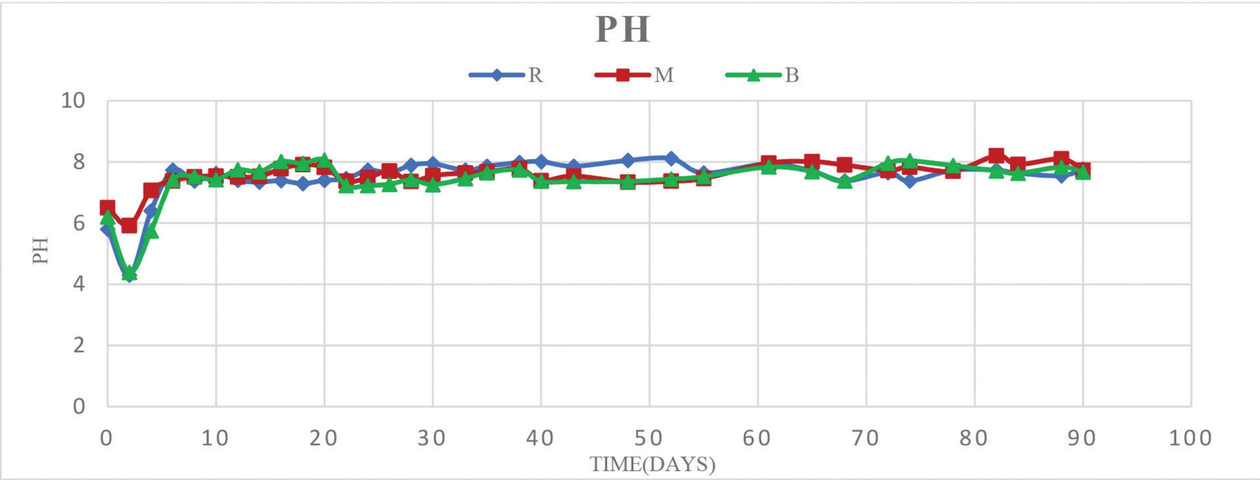


Figure 3: Change in pH value.

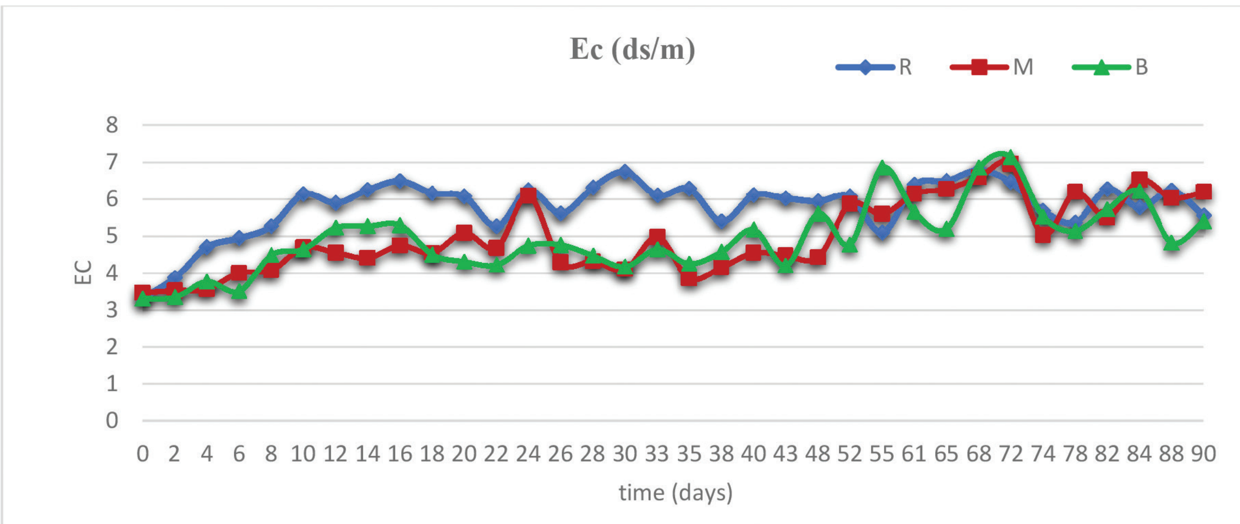


Figure 4: Electrical conductivity variations vs time.

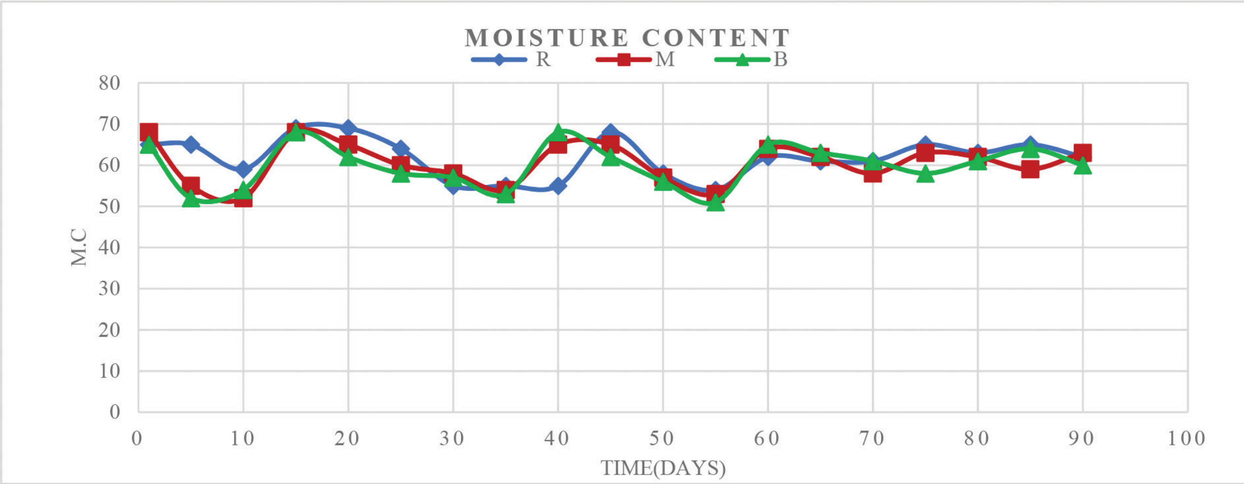


Figure 5: Moisture contents vs time.

energy intake and fast microbial development, and changes throughout the composting process, regardless of technique. As carbon is lost as CO_2, the C/N ratio typically drops and stabilises in the 10-15 range. Other chemical factors are essential for determining compost suitability, and the C/N ratio is only one measure used to assess maturity. Lower C:N causes nitrogen loss and smell, while higher ratios slow down organic material breakdown due to low nitrogen levels restricting microbial activity (Al-Zubaidi, 2013). The significant reduction in the C/N ratio (20.747, 12.431, 10.035, and 12.681) at the composting end period, is consistent with previous research (Figure 6). The C/N decreases during composting due to CO_2 conversion and a slight decrease in organic acid concentration, especially when high C/N compost is added to the soil (Chitsan et al., 2022), soil microbes compete with crops for nitrogen, decreasing growth.

NO_3^- -N & NH_4^+ -N

The C/N ratio was calculated using organic carbon and total nitrogen content. Nitrogen fractions (NH_4^+-N, NO_3^-—N), and TKN concentrations, are crucial for fertiliser efficiency (Wang et al., 2021b). The initial NH_4^+-N concentration was 350 mg/kg but increased during heating and cooling periods due to ammonia volatilisation (Figure 7b). The decrease in NH_4^+-N during cooling and maturity phases could be due to ammonia volatilisation (Machado, 2021), as NO_3^-—N also decreased in this period and nitrification microbes hardly occurred (Tiquia and Tam, 2000). However, high NO_3^--N was observed in containers: R, M, and B during the over-mature phase (90 days) (Figure 7a), indicating active nitrogen-related reactions after maturity. The

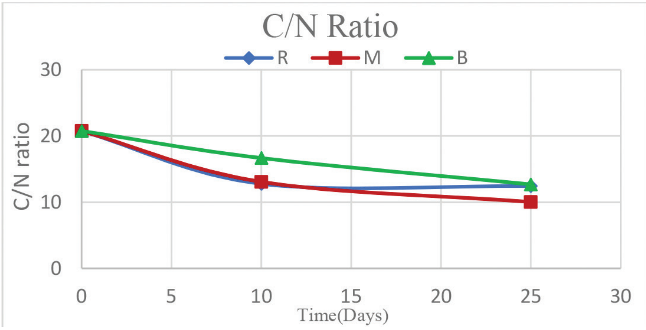


Figure 6: Variation C/N ratio vs time.

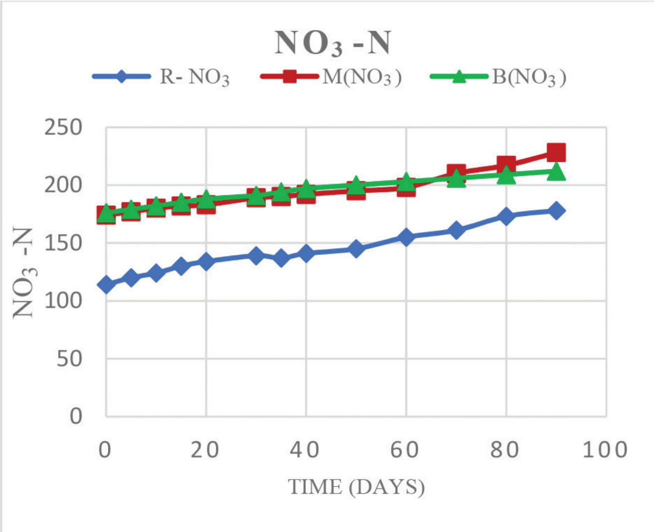
change in ammoniacal nitrogen was dependent on pH variations. TKN contents during composting and final products were higher in piles with more sheep manure in the raw material. The TKN enrichment indicates fast mineralisation of carbon fractions leads to nitrogen concentration during composting.

Total Organic Carbon

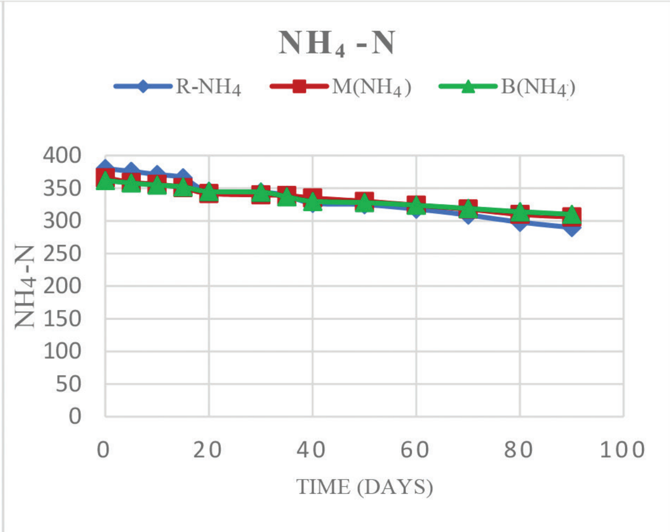
The compost's stability is determined by its total organic carbon TOC content, with R, M, and B showing a reduction of 23.18%, 22.01%, and 22.19%, respectively. The change in TOC and percent of carbon over time, Table 3 (Abraham, 2013; Black and Walkley, 1934). The initial concentration of C in R, M, B decreased by 24.1, 23.29, 23.18. The TOC highest decrease observed in all experiments, due to increased organic carbon content in composting municipal solid and food waste (Thinakaran et al., 2009), discovered a similar trend of total organic carbon decrease.

Organic Matter (O.M%)

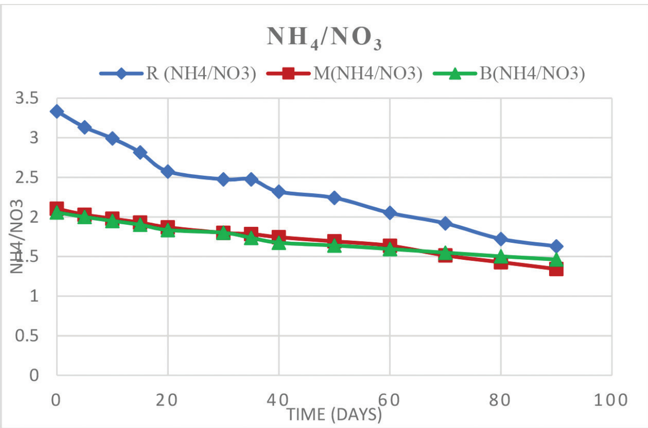
The study utilised a combustion technique to identify organic materials in the compost, drying a 2 gm



(a)



(b)



(c)

Figure 7: (a) NO_3 vs Time, (b) NH_4 vs Time and (c) NH_4/ NO_3 vs Time.

Table 3: Variation of total organic carbon

Time	*R*	*M*	*B*
0	25.13	24.43	26.18
10	24.1	23.29	23.18
25	23.18	22.01	22.19

sample in an air oven for 24 hours and incinerating it in a furnace at 550°C. Black (1965) measured the ash based on the compost's age, nitrogen concentration, and planned application, the quantity of organic matter determines the quality of the compost. The optimal amount of organic matter for compost quality depends on the compost's age, nitrogen concentration, and application. The initial and final organic matter percentage is crucial for composting as it provides an estimate of the decomposition level (Vandecasteele, 2004). The CCn procedure resulted reducing's organic matter content percentage of the substrate. The initial O.M.% of the substrate decreased 72.42%, 74.68%, 73.47%, 53.09%, 49.28%, and 45.97% for the containers of R, M, and B, respectively (Figure 8).

Nitrogen, Phosphorous and Potassium (NPK)

The NPK are the three most crucial plant nutrients for growth and production (Meena and Biswas, 2014). A high-quality compost should be free of phytotoxicants and rich in phosphorus, as a deficit can hinder plant growth, reduce disease resistance, and lower crop quality (Rizzi, 2020). The nitrogen content in compost significantly increased during composting due to the weight loss caused by CO_2 evolution during organic matter decomposition, Figure 9, Goyal et al. (2005). The study demonstrated a decrease in carbon content and an increase in total nitrogen content per unit of material during the breakdown of organic wastes (Chethan et al., 2018).

Germination Index

The germination index (GI) was calculated to assess the effectiveness of composts as plant-growing media, using 50 Cress seeds in a 72-hour dark test (Bertran et al., 2004). The experiments were conducted in triplicate, with deionized water as a control (Figure 10). The germination test was conducted on compost from trials (R, M, B), after 40 days at 65% moisture and 25 C/N ratio (Table 4), which shows Growth Index G (%) (92,88,94)% respectively; the calculated value of germination index (GI) is (88.17, 80.67, 92.04)%, respectively, Figure 11 (Tiquia et al., 1996). A GI above 80% indicates a mature compost, while low relative

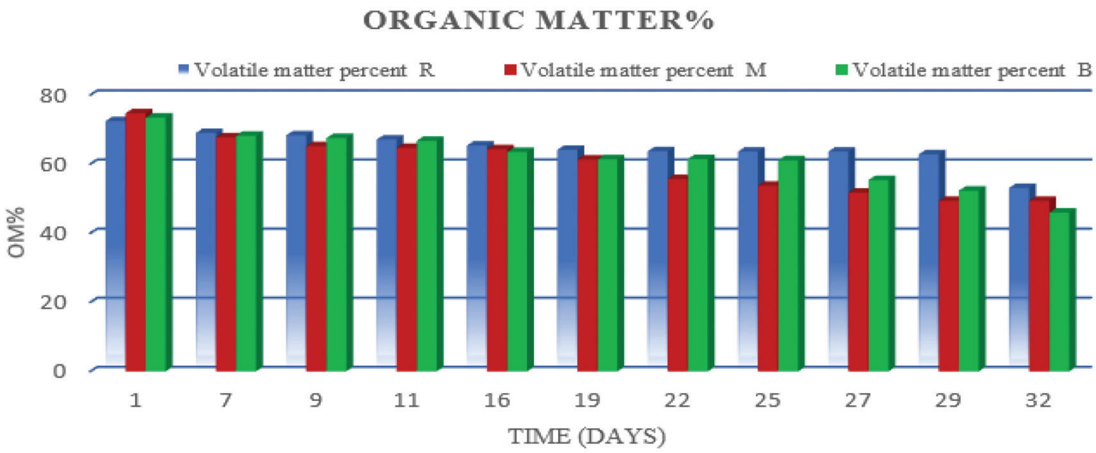


Figure 8: Organic matter vs time.

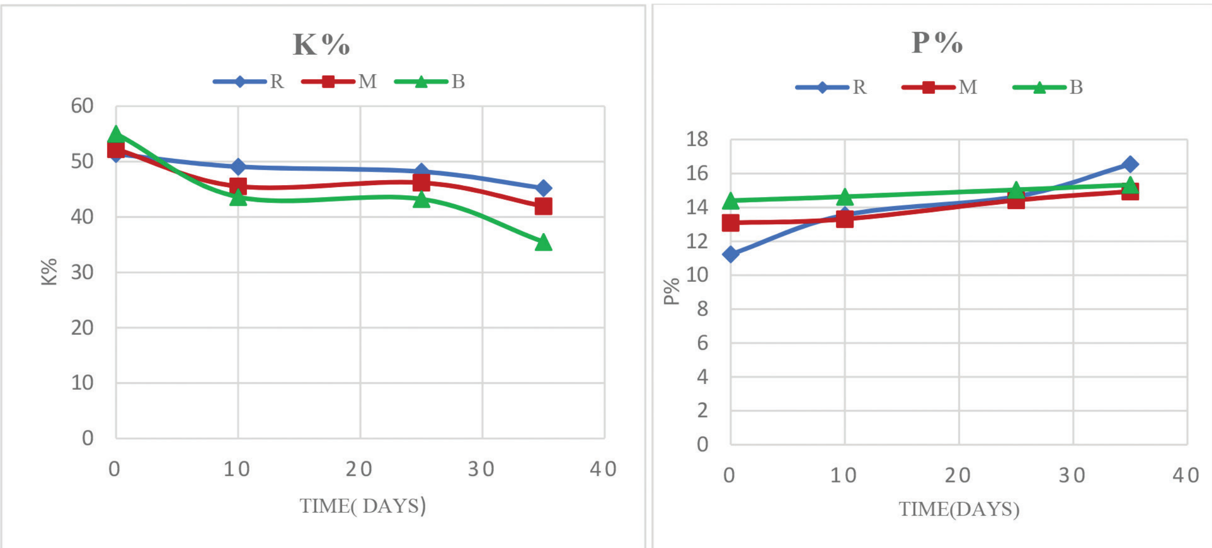


Figure 9: Phosphorous and potassium vs time.

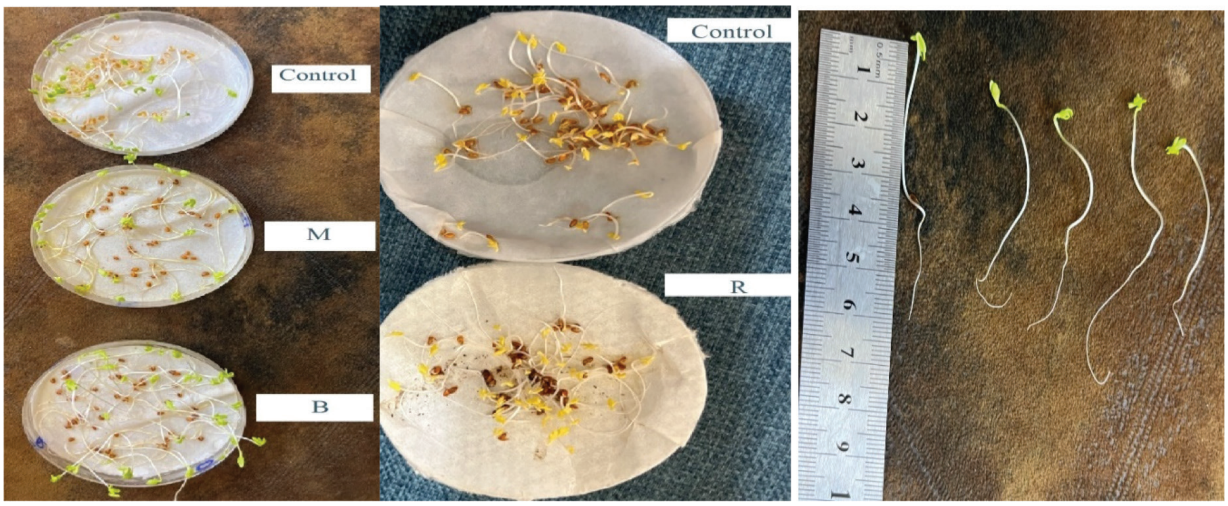


Figure 10: Germination index.

Table 4: Germination Index GI

Mixture	*Mean No. of germinating seeds*	*Growth Index G (%)*	*Mean, root length(c)*	*Root Length Index L (%)*	*Germination Index GI (%)*
R	46	92	1.951086957	95.83333333	88.16666667
M	44	88	2.693181818	91.66666667	80.66666667
B	47	94	2.436170213	97.91666667	92.04166667
CONTROL	48/50	96	1.088541667		

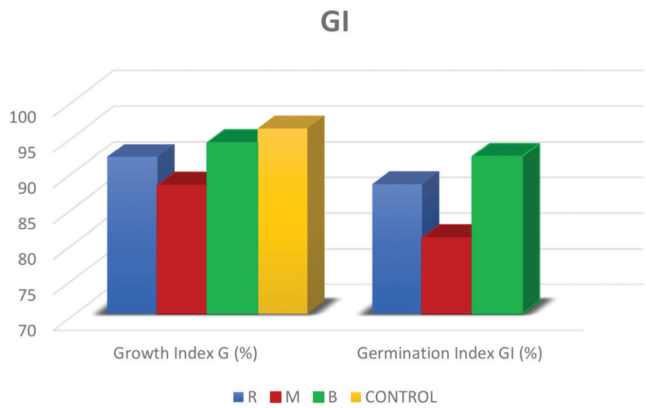


Figure 11: Growth Index G % & Germination Index GI (%).

seed germination and root growth indicate immature compost (Marek et al., 2003)

Conclusion

Composting is a good solution for expediting bioremediation of contaminated soil while removing large amounts of organic waste. In terms of waste management, application and control, creating composting procedures might help to reduce the discharge of green waste while also restoring good quality to degraded soils. From a scientific and economic viewpoint, we support the composting procedure for dirty soil remediation and green waste eradication. We believe our attempts will give important new data to help local municipalities make waste treatment and management choices. The success of the bioremediation process using compost depends on in situ features and maintaining the key parameters at an optimum level, such as the balanced C/N ratio, adjusted moisture content, and particle size. Further studies are needed to improve and develop new bioremediation applications using composting of the organic waste fraction. Chemical and biological changes in varied organic waste composting showed a succession of microbial populations dependent on the temperature obtained during composting. When paired with other data, a decrease in C:N ratio can be used as a valid indicator of compost maturity.

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