

In-Vessel bioconversion of garden waste into compost with an emphasis on process efficiency and compost quality

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Abstract

With the fast-growing urbanization efficient management of garden waste, whether at residential or social levels, has now become a challenge and an opportunity to enhance soil quality. Three different trials T1, T2, and T3 were executed constituting different forms of garden waste like un-shredded, shredded and shredded dry leaves with additives with varying processing conditions carried for 42 days using cylindrical In-vessel composters made up of HDPE. The composting process is scrutinized regularly at fixed intervals for all parameters like temperature, moisture, pH, electrical conductivity, germination index, C/N, micro & macronutrients etc. The temperature reached thermophilic in two trials T2 and T3. The pH reached the basic range of 8-8.5 in the final compost of all trials. The moisture was maintained up to 65% throughout the composting period. The trial 3 was the best combination among all the trials in which the variation of pH was (7.7-8.5), total organic carbon (42.2-35.6), total nitrogen (0.7-1.4), C: N ratio (60.3-25.4), cellulose (43.4-4.2), hemicellulose (10.2-0.9) and lignin (13.1-0.15) at the end of 42 days. The degradation rate of Un-shredded leaves was found to be very slow due large size of dry leaves. The findings highlighted that effective garden waste management is possible by following particular guidelines and it reduces the environmental impact of current disposal techniques and in addition, improves soil health using garden waste compost.

Keywords: Thermophilic temperature, Phytotoxicity, Garden waste, Shredder, Nutrients

1. Introduction

The production of municipal solid trash is progressively growing, posing a challenge for local government agencies to ensure its proper and secure disposal. The expansion of metropolitan areas has led to a rise in the amount of garden waste, including dry leaves, wood, bark, grass, and flowers. The percentage fraction of garden waste is 12 to 15% in municipal solid waste generated in India [1]. Garden waste is heterogeneous with low density (50-75 kg/m³) which occupies more space as compared to other organic waste such as vegetable waste and food waste [1]. The collection and places of disposal are the major problems with Municipal corporations, societies, and other institutes.

Composting involves the biological decomposition of organic materials into a stable, pathogen-free product without harmful microorganisms, serving as an eco-friendly fertilizer that improves soil fertility and plant growth. Current garden waste disposal methods like open dumping, incineration, and landfilling are environmentally damaging and inefficient, primarily due to complex organic compounds like lignin, cellulose, and hemicellulose. An in-vessel composting system offers a portable, rapid, and cost-effective solution for managing dry leaves [2] successfully composted banana leaves and peels with Swiss chard and soil, while [1] utilized green and organic waste in an in-vessel reactor. Further studies by [2] and [3] emphasized using banana peels and mature compost to expedite the process. Research by [4] and [5] on bulking agents, and [6] on plant biomass, highlight the need for more exploration into dry leaf composting.

While numerous studies have explored in-vessel composting of organic waste, research specifically focusing on dry leaves is limited. This study aims to fill that gap by investigating the scientific disposal of dry leaves using an in-vessel system. By analyzing all compost parameters, this research provides novel insights into the optimal conditions for composting dry leaves.

2. Materials and method

The study was conducted at Sharda University in Knowledge Park III, Greater Noida, India (latitude 28.471956°, longitude 77.483761°). The primary materials used were dry leaves collected from the Sharda University campus. Segregation and shredding to size 2-3 cms were performed at the university itself. Having the moisture content of 7 percent, carbon & nitrogen content of 32 & 0.7 percent respectively. Vegetable waste was used in one of the trials because garden waste is a problem starting from residential and

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societal level hence garden waste can be implemented as an easily available additive which was arranged from university mess itself and shredded to 2-3 cm size .This preparation step aligns with existing research [6], which emphasizes the importance of particle size in enhancing the composting process.

2.1 Rotary drum composter

Two types of rotary drum composters were used in the experiment. The first drum (D1) was a single unit with a diameter of one meter and a length of two meters. The second composter (D2) consisted of two segments, each with a diameter of two meters and a length of three meters. Both drums were constructed from High-Density Polyethylene (HDPE) for durability and resistance to corrosion. Each drum was supported by four metallic legs and featured a handle for manual rotation which was arranged to be done twice a week. To ensure thorough mixing of the dry leaves, a rotating shaft was longitudinally welded inside the drums with a slight inclination. Perforations were made throughout the drum to provide necessary aeration, promoting an efficient composting process. Both composters were equipped with a middle opening gate measuring 0.3 x 0.3 meters, allowing for easy feeding of the composting material. Effective turning of the drum was performed to maintain an aerobic environment, crucial for effective composting. This setup aligns with best practices in composting, where proper aeration and regular mixing are essential for accelerating the decomposition process and preventing anaerobic conditions, which can slow down composting and produce unpleasant odors. The complete experimental procedure is shown in the Figure 1.

Three sets of test experiments were performed for each combination, and the average value was reported. A representative sample weighing around 400-500 g was obtained from different areas of the box (top, middle, and bottom) and the sample was mixed homogeneously.

A digital thermometer was used to measure temperature at different locations. The moisture content was evaluated using the Gravimetric technique (BIS No. 10158, 1982) on a fresh sample [7] described the use of a combination of pH and EC meter to determine pH and electrical conductivity [4] measured and estimated volatile solids, carbon content, and total nitrogen.



Figure 1 Schematic representation of the experimental setup of the composting process

A flame photometer was used to measure sodium (Na), potassium (K), and calcium (Ca). Atomic Absorption Spectroscopy was used to determine the existence and concentrations of the elements Mg, Cu, Mn, Fe, and Zn. Various parameters like temperature, moisture, pH, Nitrogen, N, P, K, etc. were examined at intervals of 7 days to evaluate the degradation rate of the compost for 42 days. The different combinations of each trial are shown in Table 1.

Statistical Analysis: The significance of divergence among all physicochemical and biological parameters, was calculated using one-way Analysis of Variance (ANOVA) at level of significance less than 0.05 (p <0.05) (Table 2). For the computation of variance, SPSS 13.0 software was utilized. The initial and final results of all trials has shown in Table 3.

Table 1 Trial Composition with Quantity

S. No	Type of waste materials	Total amount of water added for moisture maintenance	Additives/ organic waste used
T1	Un-shredded dry leaf (2.5 kg)	18 liter	NIL
T2	Shredded dry leaf (5 kg)	20 liter	NIL
T3	Shredded dry leaf (5 kg)	10 liter	20 kg of vegetable waste

Table 2 Anova table for the variations of all parameters

Parameters		Sum of Squares	df	Mean Square	F	Sig.
Total nitrogen	Between Groups	.403	3	.134	11.365	.000
	Within Groups	.284	24	.012		
	Total	.687	27			
pH	Between Groups	.153	3	.051	1.283	.003
	Within Groups	.953	24	.040		
	Total	1.106	27			
Electrical conductivity	Between Groups	1859895.027	3	619965.009	2.148	.001
	Within Groups	6925375.143	24	288557.298		
	Total	8785270.170	27			
Germination Index	Between Groups	4071.429	3	1357.143	7.755	.001
	Within Groups	4200.000	24	175.000		
	Total	8271.429	27			
Total Organic Carbon	Between Groups	41.096	3	13.699	2.186	.004
	Within Groups	150.424	24	6.268		
	Total	191.520	27			
Ash content	Between Groups	137.536	3	45.845	2.840	.003
	Within Groups	387.429	24	16.143		
	Total	524.964	27			
Volatile Solids	Between Groups	137.536	3	45.845	2.840	.005
	Within Groups	387.429	24	16.143		
	Total	524.964	27			
C:N ratio	Between Groups	1510.757	3	503.586	4.199	.004
	Within Groups	2878.274	24	119.928		
	Total	4389.031	27			

df = degree of freedom, sig.=significant

Table 3 Initial and final characterization of all trials with different parameters

Parameters	Trial 1		Trial 2		Trial 3		FAI (2007) [8]	TMECC (2002) [9]
	Initial	Final	Initial	Final	Initial	Final		
Moisture (%)	6	65	11	65	70	65	35-55	35-45
pH	7.94	8.49	7.97	8.28	7.90	8.38	6.5-8.5	5.5-8.5
EC (mS/cm)	2.979	1.25	3.909	1.61	1.45	2.55	2-6	≥ 4
TVS (%)	58	73	68	70	76	64	-	-
TOC (%)	32.22	40.5	32.20	39.89	42.22	35.5	≥16	-
Total Nitrogen (%)	0.5	0.81	0.5	1.1	0.7	1.4	1.0-3.0	-
C/N ratio	64.44	50.0	64.40	35.35	60.32	25.4	< 25	≤ 25
Phosphorus (mg/kg)	1.050	1.10	1.050	1.390	1.050	1.14	0.4-1.1	-
Potassium (mg/kg)	0.590	0.96	0.590	2.890	0.590	3.32	0.6-1.7	≥ 4
Hemicellulose (%)	10.90	8.95	10.90	5.09	10.90	0.92	-	-
Cellulose (%)	43.46	39.2	43.46	6.35	43.46	4.20	-	-
Lignin (%)	13.20	11.3	13.20	0.50	13.20	0.15	-	-
GI (%)	40	100	50	100	70	100	-	-
Iron (mg/kg)	120	129	121.2	157.9	125.2	158	-	-
Magnesium (mg/kg)	248	249	248	258	250	257	-	-
Zinc(mg/kg)	191.1	200	194	248.5	194.4	248	-	-

EC- Electrical Conductivity, TVS-Total Volatile Solids, TOC- Total Organic Carbon, C/N-Carbon/Nitrogen Ratio, GI- Germination Index

3. Results and discussion

3.1 Temperature, moisture, pH, and electrical conductivity (EC)

High temperatures increase the speed of lignocellulose compound breakdown, hence it is a critical parameter in the composting process, specifically in-vessel composting [10]. All reactors experienced a thermophilic phase within a specific period, except trial T1. T2 and T3 with shredded leaves rapidly warmed above ambient temperature, reaching a thermophilic temperature of 45°C before day eight (Figure 2 A).

Moisture level is crucial for effective composting, as it influences substrate degradation and microbial metabolism [11]. The moisture content for trials T1, T2 & T3 on the first day of the experiment were noted to be 42.8, 46.2 & 77.02 percent respectively. The moisture level of T3 got a hike due to presence of vegetable waste. Maintaining the right moisture levels ensures efficient

composting by facilitating microbial metabolism and preventing slowing conditions. In experiments, moisture content was approximately 65% in all trials (Figure 2 B).

The pH level is an important indicator of compost maturity, indicating the decomposition rate of organic material, it changes significantly over the composting process [6]. The pH reached the basic range of 8-8.5 in the final compost of all trials T1, T2, and T3 (Figure 2 C).

Electrical conductivity (EC) reflects the amount of soluble salts such as ammonium, nitrate, phosphate, and potassium being released from decomposing organic material in a solution [5]. The first two trials displayed a similar trend of EC decline during composting trials, T1 and T2 were processed without additives hence their EC value ranged from 4000-1200 $\mu\text{S}/\text{cm}$, the major decline in both the trials was visible after 3 weeks while in T3 EC value first increased then decreased a bit before showing an increasing trend of EC starting from 1450 $\mu\text{S}/\text{cm}$ to attaining the highest level of 2541 $\mu\text{S}/\text{cm}$ due to the mixture of organic waste (Figure 2 D).

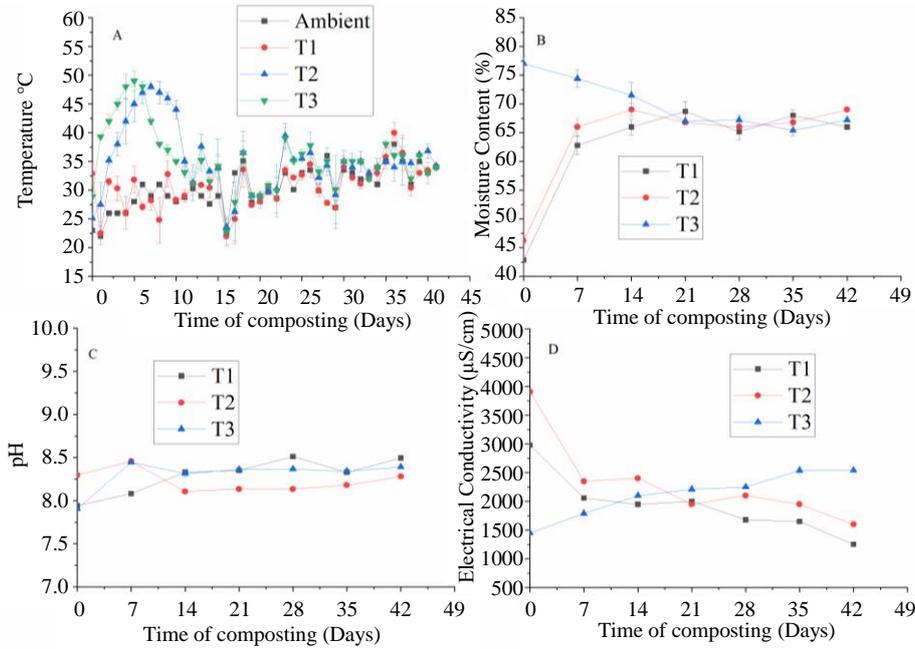


Figure 2 Variations of (A) temperature (B) moisture content (C) pH (D) electrical conductivity

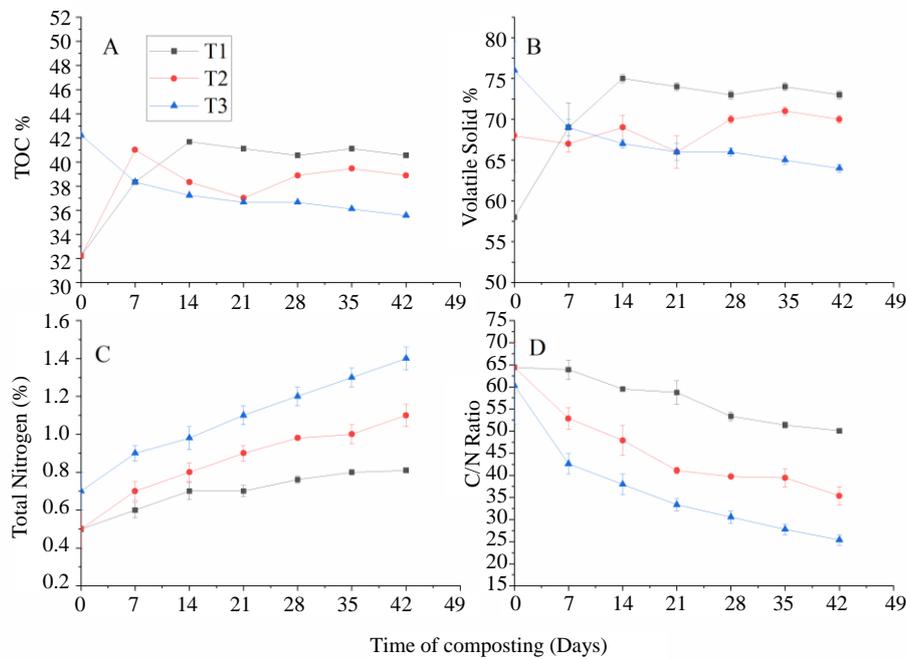


Figure 3 Variations of (A) total organic carbon (B) volatile solids (C) total nitrogen (D) C/N

3.2 Total organic carbon (TOC), Total volatile solid (TVS), Nitrogen content, C/N ratio

During composting, Total Organic Carbon (TOC) content generally decreases due to microbial carbon utilization, as bacteria and fungi adapt to free carbon in soil and decompose organic into CO_2 and H_2O with stable organics [11, 12]. The stable TOC decrease was observed in T3 from 42% to 35% in 42 days is due to higher vegetable waste content. The trial T1 and T2 showed an increase in carbon content value range from 32 – 40 percent (Figure 3 A).

Total Volatile Solids (TVS) is a measure of organic matter in a sample that volatilizes at 550°C. The case of T3 which showed a value of 76 initially and later on decreased to the value of 64 (Figure 3 B). Composting trials T1 and T2 have shown specific TVS trends, with some trials showing an increase in TVS values, while others show a steady decrease, indicating earlier mineralization of organic matter with improved composting processes [13].

Nitrogen, is an essential element for microbial growth and the activity during composting. In the experiments, the nitrogen level initially rose, then fell, and then gradually rose once again, showing a general rising trend. In all trials T1, T2, and T3 it ranged about 0.5-1.5 (Figure 3 C). The decrease in dry matter brought on by the mineralization and breakdown of non-nitrogenous organic matter during the composting process may be the reason for the rise in nitrogen content [14]. The highest nitrogen content in trial 3 comes at the beginning starting with a value of 0.7 since its source was vegetable waste [4].

Carbon-nitrogen ratio (C/N ratio) refers to the balance between carbon and nitrogen in materials being composted. Appropriate C/N ratio leads to continuous decomposition of organic matter, decrease in amount of dry matter etc. In trials T1 & T2, the C/N ratio decreased from 65 while T3 decreased from 60, indicating carbon degradation and stabilization of organic material (Figure 3 D). Among all the treatments, T3 had an initial lower C/N ratio with a value of 60.32 because of the high nitrogen content [4].

3.3 Hemicellulose, Germination Index (GI), Cellulose, Lignin

Hemicellulose was reduced in all the trials (Figure 4 A) but mainly in T2 and T3 in the heating and thermophilic phases it was quick at that time but later on slowed as the temperature reduced. T1 just showed a slight decrease in hemicellulose content (%) from 10.95 to 8.95 % at the end of the composting period of 42 days while the T2 and T3 showed a decline to a value of 5.09 and 0.92 % respectively which signifies that prolonged thermophilic phase.

The Germination Index (GI) is a measure of seed germination in compost, indicating site-specific effects related to immature or mature compost use for land application. Feedstock with a high content of biologically degradable organic matter, usually matures earlier and eventually obtains relatively-high GI values [15] as reflected in the case of third trial T3 which reflected the GI value of 100 since beginning while the trials T1 and T2 took a time of three weeks to attain the value of 100 (Figure 4 B).

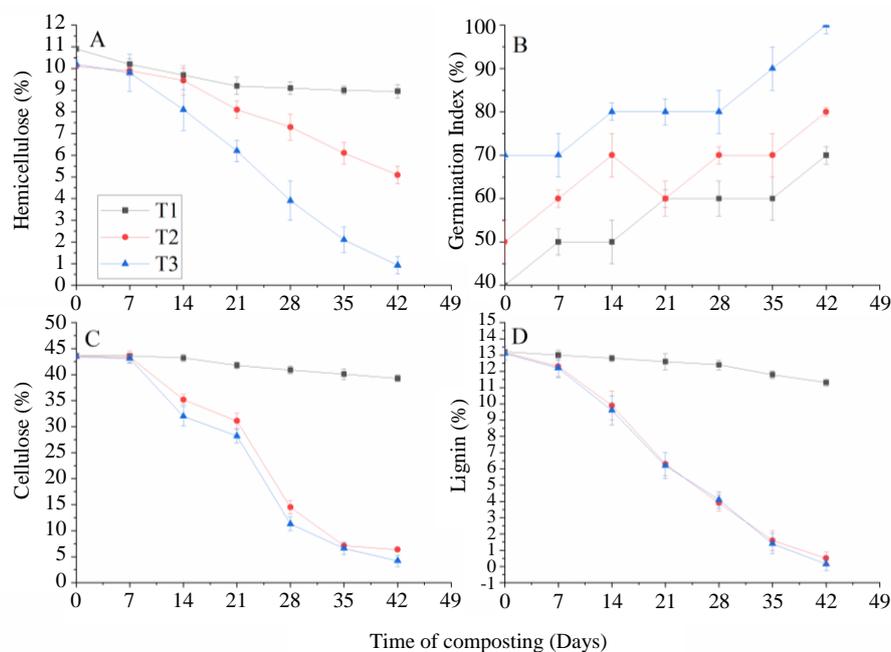


Figure 4 Variations of (A) hemicellulose (B) germination index (C) cellulose (D) lignin

Cellulose concentration decreased generally in all the trials (Figure 4 C). The microbial abundance and enzyme activity of the compost promotes the degradation of cellulose [10]. The cellulose content of T1 showed the least downfall of 4.16 % from its initial value while T2 and T3 reduced to the value of 6.35 and 4.20 from the initial value of 43.46.

Lignin content of all the trials T1, T2, and T3 showed a decreasing trend in general (Figure 4 D). But T1 reflected the lowest value of 11.3, T2 and T3 showed an almost simultaneous pattern of lignin content downfall showing final values of 0.50 and 0.15 indicating the proper degradation of garden waste.

3.4 Ash, Phosphorus, Potassium, Ammoniacal Nitrogen

Ash content essentially reflects the inorganic material present after ignition at $\pm 550^{\circ}\text{C}$. Higher ash content can be a good indicator for a greater amount of decomposed organics as reflected in the case of T3 with the value of 36 in the final day analysis. The ash content increased in all trials implying effective microbial degradation. T1 showed the least ash content reflecting the value of 27, evidencing lower organic matter degradation (Refer to Figure 5 A). Even though T3 had higher initial organic content, it exhibited maximum ash the condition implies probably because of feedstock composition or more efficient microbial activity [4].

Phosphorus plays a role in microbial metabolism, ATP synthesis, and phospholipid composition in compost. The initial phosphorus in the materials has a significant influence on the compost's final phosphorus [10]. The conducted trials found the phosphorus levels increase from 1.05-1.15 mg/kg (Refer to Figure 5 B).

Potassium (K) is a crucial crop nutrient that regulates water within plants and aids in photosynthesis. It also indicates compost quality and nutrient stabilization [10]. Trial T3 reached the max potassium value that is 3.326 mg/kg on the contrary trial T1 showed the lowest potassium value is 0.960 mg/kg, T2 showed the similar pace like that of T1 but ended at a better note value of 2.26 mg/kg (Figure 5 C).

Ammoniacal nitrogen (NH_4^+N) is a key indicator of compost maturity and quality. Ammoniacal Nitrogen in mature compost should be less than 400 mg/ kg to avoid any negative effects on safety and crop yield [10]. In the case of T1 initially, the value was 161 which decreased to the value of 60, similarly in the case of T2 and T3 the value decreased slightly from 186 to 142 and 220 to 135 respectively (Figure 5 D).

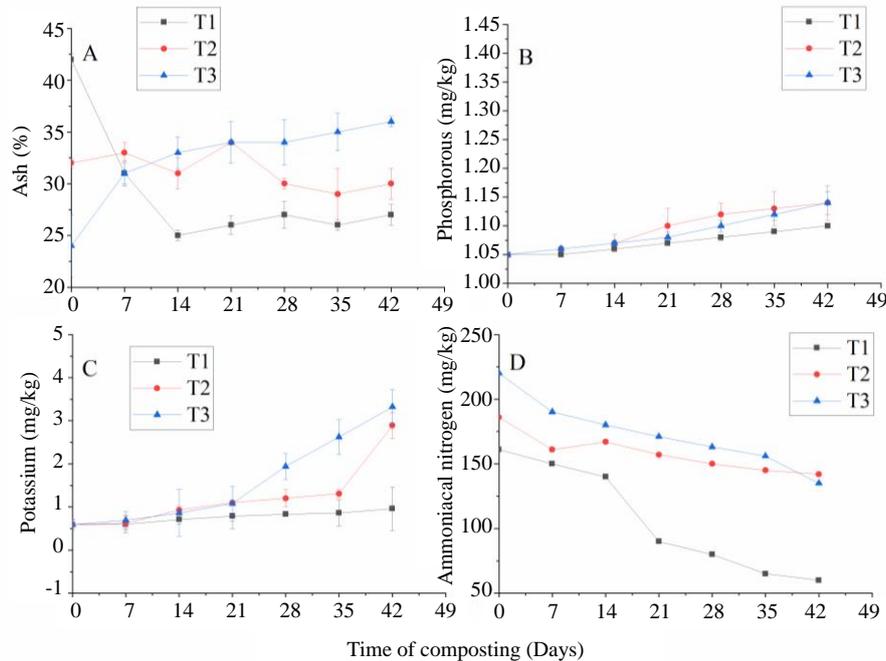


Figure 5 Variations of (A) ash content (B) phosphorous (C) potassium (D) ammoniacal nitrogen

4. Conclusion

The influences on the composting process with different plant leaf biomass form under aerated treatment were studied in this research. The main aim is to find out the effect of the addition of vegetable waste on the maturity and quality of compost. The results of the experiment confirmed the successful production of mature compost by mixing shredding plant leaf biomass with vegetable waste. Among all trial numbers T3, the one implementing shredded plant leaf biomass with vegetable waste as an additive was demonstrated to greatly enhance the composting process though this method seems to be fine at the residential and societal level but it will be quite tedious at the municipal level as ratio of garden waste and vegetable waste is taken as 1:4. While T1 didn't show any promising results may be because of the presence of unshredded form of plant leaf biomass which didn't provide an efficient opportunity for microbial activity.

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