Bio-Valorisation of Urban Organic Waste Through Composting

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I, AKSHITA KHARE, Roll No. 2K20/ENE/02 of MTech (Environmental Engineering), hereby declare that the project Dissertation titled "**Bio-Valorisation of Urban Organic Waste Through Composting**" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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ABSTRACT

With growing population, advancement in technology and increase in public demand for commodities, there is insurgence in the rate of generation of waste globally. The municipal solid waste has a major contribution towards the rising issue of waste management which comprises of around 47.4% organic part, that is biodegradable. Through extensive literature review, it has been inferred that composting is the most economically efficient and sustainable method to treat the organic waste. Through the study it has been found out that the rate of compost formation and its characteristics are dependent on various parameters including temperature, pH, moisture content, C/N ratio and aeration. Lignocellulosic biomass is a plentiful and difficult-to-degrade renewable resource. White rot fungus (*P. chrysosporium),* a lignin-degrading fungus, degrades lignocellulosic waste has been cultured in the laboratory to inoculate the plant biomass to increase the rate of decomposition.

The pH in the end of the analysis period was 7.31 and 7.15 for inoculated and uninoculated yard waste. The temperature was maximum on 128th day for inoculated waste which was 67.2°C and for the uninoculated yard waste the temperature was highest on 150th day and was found to be 46°C. Composting is a cost-effective method for the treatment of organic waste, as the cost of production of crop by using synthetic fertilizers exceeds the cost of production by using organic manure. The cost benefit analysis, using compost as a fertilizer was done comparing the cost of production of crops using synthetic fertilizers and the calculated profit was 0.66%. Composting not only minimizes the waste generated, but also helps in the ecological sanitation, cost reduction and employment generation, thereby upholding the concept of circular economy that deals with sustainable living in terms of social, economic and environmental aspects. A part of initiatives and policies formulated by several countries to abide by the concept of circular economy have been incorporated in the study.

KEYWORDS: Composting, Circular Economy, White Rot Fungus, Inoculum, Cost-effective

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ABBREVIATIONS

BA	Bulking Agent
CE	Circular Economy
DAP	Diammonium Phosphate
ECOSAN	Ecological Sanitation
GHG	Greenhouse Gas
GWP	Global Warming Potential
PDA	Potato Dextrose Agar
TGA	Thermogravimetric Analysis
TKN	Total Kjeldahl Nitrogen
VOC	Volatile Organic Compound

INTRODUCTION

Environmental quality has become a major concern around the globe since the time development has gained pace. With the improvement of economies issues like air pollution, contamination of water resources, ineffective solid waste management and dwindling natural resources are being faced uniformly around the globe. This further aggravates the problem of deteriorated health among people. As reported by the World Health Organization (WHO) air pollution has resulted in 4.2 million deaths per year, as global burden (WHO, 2021), the consumption and non-availability of safe drinking water cause 4,85,000 deaths per year due to diarrhea itself, whereas 2.5 billion global population consume faecal contaminated drinking water (WHO, 2022).

Despite being global challenges to meet the sustainability development goals of “clean water and sanitation” and “sustainable cities and communities”, respectively for air and water, there is no direct/significant scientific relation of water and air quality affecting each other. But unmanaged waste has a direct bearing on quality of water, air, soil and organisms which interact through different natural processes. Therefore, management of solid waste has come up as a daunting task for the management of environmental quality.

As on date, approximately 2.01 billion tons of solid waste is produced on daily basis, out of which only 67 percent is being treated/managed (The World Bank, 2022). The uncollected/non-treated waste, thus, interacts with water, soil, and air through the processes of run-off, photo- and biodegradation, and refuse burning, respectively which results in deterioration of environmental quality. The proper waste management is essential since it causes positive feedback to problems of poor air quality, chocking of water bodies, contamination of land, reduced soil fertility, respiratory disorders, toxicity laden food and poor health, particularly in urban areas.

Urbanization and economic development have led to the enhancement of the well-being of a major fraction of global population. Consequently, there is a significant increase in the materially intensive resource consumption and also, in the amount of waste generated worldwide (Singh, et al., 2014). The developing nations, dealing with burgeoning populations, denting land availability and resource scarcity, are bound to face a rapid growth in the cost incurred in the management of waste produced, involving its collection, transportation, treatment and disposal. Due to increase in the quantity of waste produced, over stressing of land and financial instability, has become a major cause for economic burden, globally.

Strategically, the waste and resource management currently follow the linear economic model to handle the waste produced, in most of the developing nations. This does not follow a holistic approach curtaining the complete production chain, including the disposal of waste (Paes et al., 2019).To ascertain the sustainability and the consumption and utility of the resources, without compromising with the needs of future generation, it is important to shift from linear to a Circular Economy model, conserving its original value, without its leakage to the environment.

Proper treatment and management of waste demands proper characterization, on the basis of its calorific value, recyclability, toxicity and other physical, chemical and biological parameters. Major portion of the organic waste includes kitchen waste, agro – residues, and the leftover food from restaurants and industries. India being the second largest agro based economy followed by China, serves nearly 58% of its total population. With the growing population the demand for the total agricultural produce is also increasing which needs to be cultivated on a large scale to meet the daily needs of the population.

The cultivation of crops produces a significant amount of crop residue (agro waste), which is an important issue of concern as the treatment of waste includes burning of the crop residue, degrading the ambient air quality as harmful gaseous emissions are released to the environment, also affecting the health of the people residing nearby, including the workers in the agriculture sector. Around 824 Gg of PM2.5 and 211Tg of CO_2 equivalent greenhouse gases are emitted with the burning of crop residues in India (Ravindra et al., 2022). In the year 2019, the amount of crop residue generated was approximately 141 million tons per year out of which around 92 metric tons was burnt, mostly in the states of Punjab and Haryana (Avtar Singh Bimbraw, 2019). Keeping in view the problems mention above related to waste management, it is necessary to study and implement the methods which are economic and environment friendly. Composting is an alternate sustainable and profitable solution to treat and manage the organic waste. Around 1.5 thousand centralized wastes to compost plants were operational in India as of December 2019. Waste to compost plants transform biodegradable organic waste into nutrient-rich compost (Tiseo, 2020).

The process of composting is a cost-effective and eco-friendly method to manage the municipal solid waste generated. But, composting of plant biomass is a matter of concern due to its complex structure which is made up of lignocellulosic compound, that is difficult to degrade, unlike other organic raw material. The rate of decomposition of the plant biomass is generally slow when occurs naturally, until any catalyst or treatment method is applied. This delay in composting, encourages the farmers/waste collectors to burn the straw or crop residue instead of treating the same. This study deals with the issue related to the decomposition of plant based raw material such as grass clippings, twigs, etc., with an attempt to find solution that is practicable.

The study is designed to meet the following objectives:

- To study and understand the management of organic waste (lignocellulosic plant-based waste) through composting in a cost-effective and environment-friendly manner.
- To analyse the physical and chemical characteristics of the yard waste, during composting.
- To put forth the concept of 'circular economy' as a restorative model proposed to minimise organic waste and establish a relationship between Composting and the Circular Economy.
- To subsequently analyse the social, economic and environmental benefits of composting.

REVIEW OF LITERATURE

2.1 Overview

The municipal solid waste/urban waste is a combination of organic(decomposable) and inorganic(recyclable) fraction. The inorganic part (non-putrescible) comprises inert matter and recyclable matter, whereas the organic part (putrescible) is approximately 47.4%, which is degradable (CPHEEO, 2016), which is a valuable source to recover resources useful for energy production (bio methanation), soil husbandry (aerobic/anaerobic/vermicomposting), ecological sanitation and socio-economic equilibrium.

The most appropriate and manageable approach towards minimization of organic waste is composting. If practiced on site, a significant amount of waste can be treated locally, without diverting it to the landfills, overcoming the issue of treatment and management of mixed waste, including segregation and characterization, transportation and disposal (Adhikari, 2013). Composting is economically beneficial, as it helps in the reduction of the cost incurred during the complete process of treatment of waste involving various series of events including collection, transportation and disposal, following the economic model of circularity which aims towards sustainable management, through recycling and reusing the waste generated from the production of a product till its end of life.

2.2 Composting

Composting is the degradation of organic matter with the help of micro-organisms which takes place during the aerobic respiration and thermal decomposition of the biodegradable waste. Following equation (1) is associated with the composting process (Neugebauer & Sołowiej, 2017)

$$\mathbf{Organic\ waste + enzymes + O_2 \xrightarrow{\text{in the presence of m/o}} H_2O + CO_2 + compost + heat} \quad (1)$$

The end product is the compost, which is a rich source of nutrient, that helps in the plant metabolism, soil nourishment, improved air quality and ecological sanitation. Compost can be used as a soil amendment and bio-fertilizer, replacing the synthetic chemical fertilizer, production of which causes emission of noxious substances, which can cause poor environmental health. Compost is mainly used in agriculture/horticulture, where it is meant to deliver nutrients to the soil in organic form, for the maintenance of soil health (Finstein &

Morris, 1975). The positive impact of composting over the environment, is the overall reduction in the GHG emissions during the transportation of waste and its disposal in the landfills. Composting can also help in reducing net CO2 emissions, by the process of carbon assimilation/fixation in soil. The process of composting demands treatment of organic waste that is managed in a controlled manner, leading to the production of carbon dioxide, water, minerals and compost (stabilized organic matter). The process of composting is completed in two phases. The first phase is the decomposition phase, where the easily degradable organic matter is oxidized. The second phase is the stabilization phase which involves mineralization and humification of cellulosic compounds that contain lignin (Insam & de Bertoldi, 2007). There are several other factors which affect the rate of composting by regulating the activity of microorganisms. The effect of each factor is discussed as given below.

2.2.1 Temperature

Temperature plays a vital role in the production of high/rich quality fertilizer (compost), as it is proportionate to the rate of decomposition of the organic matter. The beginning of microbial degradation process, implies the rise in the temperature of the organic pile, which is due to the metabolism of the enzymes, which is exothermic in nature and produces heat. There are mainly two mesophilic stages and a thermophilic stage of temperature variation, which is the most essential component of composting. The mesophilic phase is the first phase (25-40˚C), where the primary decomposers (fungi, bacteria and actinobacteria), break down easily degradable sugars and proteins. The mesophilic organisms are more in number, than the thermophilic organisms in the initial stage, thus, activity of the mesophiles increases the temperature(Insam & de Bertoldi, 2007).

The second is the thermophilic phase (35-65˚C) where the rate of decomposition increases with an increase in the temperature. The growth of fungi is inhibited at higher temperature, whereas bacteria and actinobacteria, which are thermotolerant and thermophilic, dwell even at high temperature range. The temperature should not exceed the desired range as it may even kill the microbes required for the degradation of the organic matter. Therefore, regular turning of the compost pile must be done to avoid the temperature rise, and also to distribute the heat uniformly, as the central part of the pile is the hottest among the other areas (Insam & de Bertoldi, 2007).

The third phase is the second mesophilic phase (cooling phase) where the substrate tends to exhaust, bringing the decomposition process to an end. Recolonizing or reproduction of mesophiles takes place due to living spores or catalytic enzyme (inoculum). Both bacteria and fungi are responsible for degradation of starch or cellulose at this stage (Insam & de Bertoldi, 2007). Finally, the process gets stabilized and a mature, dark textured and nutrient rich product is obtained i.e., compost.

2.2.2 pH

pH is an important factor to regulate the rate of degradation as it facilitates the activity of microorganisms which are responsible for the decomposition of organic matter. The microorganisms best operate under acidic to neutral conditions and the acidophiles are mainly responsible to initiate the process of decomposition in the beginning.

During the initial phase of composting, pH of the pile decreases (4.5-6) due to the formation of organic acids (Nakasaki et al., 1993). The acidic conditions favor the growth of fungi and other microorganisms, to feed upon the organic matter to increase the rate of decomposition.

As the process continues, the pH gradually increases due to volatization of organic acids and mineralization of organic nitrogen to ammonia (Finstein & Morris, 1975; Forsyth & Webley, 1948; Hoyle & Mattingly, 1954). Increase in NH_3 is the result of increase in pH and hence rate of volatisation increases showcasing rapid degradation (DeLaune et al., 2004; Onwosi et al., 2017). The optimum pH value suggested is nearly in the range of 5.5 to 8 for the microbial activity to take place in an effective manner (Chen et al., 2015; Onwosi et al., 2017). Alkalinity in excess, may cause hindrance in the growth and survival of micro-organisms, which dwell in conditions favored in low pH range (Hachicha et al., 2009). After completion of the composting process, the pH of the compost stabilizes within the range of approximately 7.0 to 9(Finstein & Morris, 1975).

2.2.3 Moisture content

Moisture content is a critical parameter in the process of composting. The rate of uptake of oxygen, activity of microbes, air voids and temperature are influenced by the moisture content (Onwosi et al., 2017; Petric et al., 2012).The availability of moisture is the result of metabolic activity and evaporation, which take place during the composting process (Finstein & Morris, 1975). Moisture content is a supportive measure towards rate of decomposition of organic matter. The optimum moisture content, suitable for a good quality compost, should be 50-60% (Finstein & Morris, 1975). The rate of diffusion of gas is reduced on increasing the moisture content, reducing the free air spaces causing anaerobic conditions, affecting the uptake of oxygen and metabolic activity.

The temperature also gets altered with the change in the percentage of moisture present in the organic matter, as temperature and moisture content follow an inverse relationship (Onwosi et al., 2017; Sudharsan Varma & Kalamdhad, 2015). The loss of moisture from the biodegradable organic fraction, assists the decomposition process. The hinderance caused in the biological process of the microbes, is the result of very low moisture content available for proper degradation (Onwosi et al., 2017).

The most important component for the plant growth and soil enhancement are the nutrients which are easily absorbed when in soluble form. The moisture content helps in dissolving the nutrients well within the soil structure, to make the uptake easy for the micro-organisms, to increase the efficiency of the degradation process of organic matter (Guo et al., 2012; Onwosi et al., 2017).

2.2.4 C/N ratio

During the process of composting the micro-organisms break down the organic matter into simple compounds to obtain energy for the process of metabolism and nutrients such as nitrogen, potassium and phosphorus to proliferate. However, carbon (C) and nitrogen (N) are the most important, as carbon provides energy, and nitrogen acts as building block for the microbes, therefore, C/N ratio is important in determining the degree of decomposition of organic matter. Carbon is lost as CO_2 due to oxidation of organic molecules, whereas deficiency of nitrogen can affect the rate of decomposition of the organic matter as it is important for the growth of the microorganisms (Lazcano et al., 2008).

There is an increase in the C/N ratio, during the process of composting as the rate of mineralization of organic nitrogen is less than that of carbon (Onwosi et al., 2017; Yang et al., 2015). The C/N ratio should be in between 25:1 to 40:1 to maintain the optimum nutritional value of the compost (Finstein & Morris, 1975). The C/N signifies that the rate of consumption of carbon by the micro-organisms is 25-40 times more than the rate of consumption of nitrogen. If the C/N ratio is lower than the defined range, it will lead to the formation of ammonia (NH_3) in excess, resulting in nuisance causing odors. NH_3 formation depends on pH and temperature, where, it is favored in high temperatures and alkaline conditions (Cerda et al., 2018; Pagans, Barrena, et al., 2006) and if the ratio is more than 40:1, then the compost would become nitrogen deficient. Bulking agents (such as urea, rice husk and wood chips) can be effectively used to provide proper aeration and maintaining the C/N ratio (Cerda et al., 2018; L. Zhang & Sun, 2016). If the degree of decomposition of organic waste is more the C/N ratio will decrease accordingly (Lazcano, Gómez-Brandón and Domínguez, 2008; Onwosi et al., 2017).

2.2.5 Role of Microbes

Composting is the aerobic degradation of organic matter, where the main operators/microorganisms play an important role in the decomposition process. The organic waste/substrate is the food for micro-organisms, that is rich in nutrients (N, P and K) and energy, which they feed on and multiply. The enzymatic activity of the micro-organisms depends on the type and nature of the waste that is to be degraded. Lignocellulosic compounds are complex in structure, so it is difficult to decompose them, that results in incomplete composting. There are certain micro-species that develop either naturally in the environment suitable for their growth or are cultured in the laboratory simulating the similar conditions, which are required specifically to breakdown such complex molecules. Certain fungal species, such as white rot fungi (*P. chrysosporium*), are efficient in degrading lignocellulosic compounds due to the presence of certain oxidative enzymes.

The microbiota mainly comprises of bacteria and fungi, as the major species, along with other micro-organisms which dwell depending upon the ambient conditions suitable for survival. Bacteria are dominant over fungi, as few bacterial species (*B. Stearothermophilus*), can survive even at high temperature, decomposing a considerable amount of organic matter in the initial phase of composting. The bacteria perform best in the temperature range of nearly 50 - 65˚C. Actinobacteria is able to degrade relatively complex compounds, which is favored in slightly alkaline medium. These are thermophilic and operate under high temperature ranges, preferably greater than 45˚C (Insam & de Bertoldi, 2007). During the initial phase of composting fungi and bacteria, both actively contribute in the decomposition process, bacterial colonies being substantially more.

The temperature range that favors the growth and activity of fungi lies approximately between 25˚C to 48˚C (Finstein & Morris, 1975). Fungi are less thermotolerant, hence their vitality during thermophilic stage reduces. Exceptionally, the certain species, which are responsible for the degradation of lignocellulosic compounds, remain important throughout the composting process (Insam & de Bertoldi, 2007). However, turning of the pile at regular intervals, provides proper aeration and help in increasing the rate of microbial growth and decomposition of organic matter (Cerda et al., 2018).

2.2.6 Aeration

Aeration/supply of O2 is a critical component of composting as the process is directly associated with the microbial activity, which requires proper aeration to grow, to increase the efficiency of decomposition of the organic matter (Cerda et al., 2018; Nakasaki & Hirai, 2017) .The rate of aeration affects the degradation rate, heat loss, percentage of moisture, temperature, thus affecting the microbial dynamics and quality of compost (Guo et al., 2012; Onwosi et al., 2017).Particle size and porosity also plays an important role in aeration. The porosity should be optimized for effective water holding capacity and water and gas exchange in the compost (Cerda et al., 2018; Ruggieri et al., 2009). Inadequate porosity may lead to clogging of voids due to water, creating anaerobic conditions, consequently causing issues related to odor and promotes methane (CH_4) formation (Adhikari et al., 2008; Cerda et al., 2018). To avoid the developing anaerobic conditions, use of bulking agents, such as wood chips, saw dust, rice husk, plastic pipe, etc., would provide proper aeration and free air space.

Green waste has come out to be a major part of the municipal solid waste with an increase in development of the urban green areas. The challenge is to manage and treat green waste in a sustainable manner, as it comprises of lignocellulosic compounds which slow down the decomposition process, when being composted. Green waste (tree bark, grass pruning, leaves, grass clippings etc.) has low bulk density, therefore it is difficult to collect and transport to the landfills or any treatment site, thus increasing the cost incurred in the management process (López et al., 2010; Oviedo-Ocaña et al., 2019). Composting is one of the effective ways to treat green waste and it can be less time consuming if the lignocellulosic waste is enzymatically processed (inoculation) before it undergoes the microbial decomposition indigenously (Jurado et al., 2015; Oviedo-Ocaña et al., 2019). Amending green waste with processed and unprocessed food waste (co-composting) proportionately, can accelerate the rate of degradation and the thermophilic stage could be achieved in lesser time than usual. In addition, the other important regulating factors associated with composting such as C/N ratio, essential nutrients (N, P, K), moisture content etc., are optimized to make the product suitable for agricultural use. Also, inoculation with microorganisms, which are capable of degrading lignocellulosic compounds, can improve the rate of aerobic decomposition and quality of the compost (Oviedo-Ocaña et al., 2019).Composting is recommended largely, for it can be practiced even at small scale (household level), providing a suitable temperature and other necessary conditions, that are optimized to carry out the microbial dynamics, for the proper degradation of organic waste. Composting at household level involves food waste produced from the kitchen and green waste that is generated from the garden. The final product obtained (compost), is a high-quality fertilizer, which is organic in nature and can be utilized for the conditioning of the soil at local level and if required, could be effective in carrying out horticulture, cultivating plants for food and medicinal purposes keeping the surroundings hygienic and pathogen free. The green waste (garden waste), acts as a bulking agent, providing proper aeration to the mixture to avoid odor nuisance and to maintain the temperature and moisture content. The major challenge in composting at household level, is that residents may not be able to differentiate between waste that is suitable for composting which may result in increase in greenhouse gas emissions and odor due to ammonia. It is advised to use closed containers and bulking agents, to minimize the problem of odor due to ammonia emissions (Bergersen et al., 2009; Neugebauer & Sołowiej, 2017). The advantage of in-house composting is that it does not require any specific and advanced technique for treatment and recycling of organic waste. Also, it is helpful in reducing the cost incurred and minimizing the release of toxic substances to the environment during the process of handling, during collection and transportation of waste to the landfills and other treatment facilities (Neugebauer & Sołowiej, 2017).

2.3 Application of Composting

Compost can be used as a fertilizer and enhances the soil quality, as it is a rich source of energy and nutrients such as carbon, nitrogen, phosphorus and potassium, that helps in carrying out metabolism to promote growth of the plants. Compost being used as biofertilizer can potentially replace nearly 30% of synthetic fertilizers which are phosphate based (Chia et al., 2020; Mieldažys et al., 2019). The water holding capacity of compost benefits the soil in a way that the moisture is retained in the soil structure which balances the pH and keeps it hydrated, nurturing the soil for good quality yield. The cow manure is considered a valuable soil conditioner, but compost obtained from the food waste is known to be a better source to restore and replenish the soil with nutrients.

The massive exploitation of fossil fuels has resulted in their depletion in the next five decades as their rate of consumption has become much more than their rate of production (Cheng et al., 2020; Chia et al., 2020). Therefore, there is a need to shift towards a sustainable and renewable source of energy/bioenergy through composting of food and agriculture waste. The anaerobic digestion of municipal solid waste can be used to produce energy with the help of the biogas produced, in a controlled manner. Composting involves aerobic decomposition of organic matter through micro-organisms, which is effective in minimization of waste, recovery of resource and balancing the nutrient cycle. Composting results in yield of good quality and fibrous crops which are a good source of energy to the consumers and also, the performance of plant microbial fuel cells is improved that help in the production of bioelectricity.

The water holding capacity of compost is significantly much more than its own weight, therefore, it not only nourishes the soil, but also helps in the revitalization of nearby water resources as the filtered water percolates down the layers of the soil and rock and recharge the local springs, lakes and ponds. Commercially, composting is considered as a cost effective and economical method to treat the organic waste as it aids in reducing the transportation and disposal cost of municipal solid waste in urban areas. The mass and volume of solid waste through composting is reduced nearly by 25-60%, thereby minimizing the cost of treatment and management of urban organic waste in developing countries (Harir et al., 2015). The economic potential of composting can be projected also in agriculture sector, to the farmers. The chemical fertilizers which are being used by the farmers as a nutrient supplier in the field can be replaced by natural fertilizer/bio-fertilizer produced as compost, to avoid the dispensable cost of production and consumption of the chemical fertilizers. The process of composting comprises of series of economic activities, which would require engagement of labor, subsequently increasing employment and quality of work. The farmers are benefitted, as the reduction in cost in the collection, transportation and disposal of municipal solid waste, in a way increases the farmer's income and also helps to alleviate the poverty in rural areas.

Composting can prove to be an alternative to burning of agro-residue or crop-residue, especially during winters, which causes the release of toxic substances and deteriorates the ambient air quality, causing air pollution. The rising population has resulted in increased demand for food, hence an increment in the production of food crops is required which will eventually lead to the generation of crop residue extensively. Approximately 15.9% agricultural residue was burnt in India in the year 2014 (Jain et al., 2014; Ravindra et al., 2019).Crop residue burning is another major source of emission of air pollutants and GHGs, which are the major source for climate change and global warming (Ravindra et al., 2016, 2019).

The process of composting is essential in recovering the resources in the form of food and bio-energy by providing necessary supplements to the soil for the proper growth of the crops/plants and also recovering energy from the gaseous emissions taking place during the biodegradation of organic matter. The agro waste generated can be utilized to manufacture briquettes in the industries, the municipal solid waste collection and segregation and the process involved in the production of compost, require significant number of labors, generating employment. The increase in the number of people involved in the application process of treatment of waste lead to the formation of valuable product improving soil health and quality of environment. Composting helps in providing environmental sanitation service and ecological sanitation which has become a global challenge, due to rapid population growth, depleting resources and environmental degradation (Hu et al., 2016).

ECOSAN (Ecological Sanitation) is a method of using animal excreta with the household organic waste to be generally used in agriculture, for the purpose of soil nourishment, by closing the material flow cycles. Composting of animal excreta along with the organic waste helps in the degradation process in a more effective manner with an optimum C:N ratio and other nutrients required for the microbial activity of the micro-organisms. The urea obtained from the animals, is a rich source of nitrogen, used as an essential component/nutrient by the plants. The disease-causing pathogens are killed during the process of composting, as they are unable to survive high temperature ranges.

The variations in pH and moisture content also affect the inactivation of the pathogens, subsequently sanitizing the local environment (Hu et al., 2016; Martens & Böhm, 2009). The municipal solid waste contains pathogens which are harmful for the human health, therefore, ecological sanitation through composting helps to minimize the risk of health to the people residing nearby. Therefore, composting of organic waste/municipal solid waste leads to minimization of waste at each step of treatment of organic fraction, improvement of environmental quality and soil health, generation of employment cost reduction and economic growth, justifying the concept of circular economy in both developed and developing countries.

2.4 Major Challenges in Composting

2.4.1 Non-homogeneous composition of food waste

The composition of food waste is likely to be heterogenous, comprising both organic as well as inorganic substances, which may slow down the rate of decomposition by the microorganisms. The moisture content, of the non-uniform food waste is relatively high (74-90%) with low calorific value, along with the C/N ratio in the range of 14.7-36.4 (Adhikari et al., 2008; Cerda et al., 2018). The presence of inorganic substances not only impedes the process, but also exhibits the amount of impurity (glass, plastics, metal etc.) present in it, which could consequently affect the plant growth and overall environmental quality. Also, the impurities larger in size, pose a direct health impact on the people concerned with the handling of the mixed waste during the process.

To minimize the percentage of impurities, present in the mixed waste fraction, the most effective method is source segregation. The organic and inorganic part of the municipal solid waste should be separated at source, by the waste generators itself, so that the toxic laden substances and non-degradable matter could be minimized and the environmental damage could be reduced (Cerda et al., 2018; Huerta-Pujol et al., 2010). The communities must be provided with appropriate knowledge/awareness, about the fraction of waste responsible for the depletion in the economy of the global waste management system, so that the waste could be segregated at source, in a proper manner, based on toxicity, recyclability and degree of biodegradation.

2.4.2 Odor and Gas Emissions

The process of composting is incomplete without the emission of certain gases and is never odor free. Release of some gases to the environment including H_2S, NH_3, CH_4, NOx, CO, and VOCs (terpenes, aliphatic carbons, aromatic hydrocarbons, esters and ketones), not only affects the quality of air surrounding the composter but, also causes discomfort to the public residing nearby (Cerda et al., 2018; H. Zhang et al., 2016). There could be negative health impacts and respiratory problems associated with the odor produced which could affect the cost of treatment and quality of living. Odor being the by-product of the biodegradation of organic matter by the microorganisms, in the process of composting, is unavoidable and is also responsible for the GHG emissions as some odorous compounds/gases such as CH_4, N_2O and certain VOCs possess high Global Warming Potential (GWP), being one of the reasons for climate change (Onwosi et al., 2017).The most prominent odor causing compound is ammonia (NH_3), which is a colorless gas, produced by the decomposers, which is released in excess due to low C/N ratio (Cerda et al., 2018; Zang et al., 2016). The thermophiles accelerate the rate of decomposition and the process of mineralization occurs at a faster pace, thus emission of ammonia gas is more dominant at high temperature (thermophilic) and high pH (alkaline) range.

The raw material/substrate characteristics also play an important role for the estimation of the measure of gaseous emissions, occurring during the composting process. The organic matter rich in odorous compounds would contribute to the environmental pollution more.

Rate of aeration is the main factor affecting the emission of VOCs, as improper supply of oxygen could result in anaerobic conditions, thereby emitting more volatile odorous compounds.

Frequent turning of compost pile could provide proper aeration, which would oxidize the pollutants reducing the emission of odorous compounds, particularly VOCs. Use of bulking agents (B.A.) adequately, could provide sufficient free air space, reducing odor during the composting process. Biochar (pyrolysis of organic waste) is an alternative to reduce ammonia emissions, as it not only helps to increase rate of decomposition, but also acts as an effective bulking agent (Chowdhury et al., 2014; Janczak et al., 2017; Khan et al., 2014; Mandal et al., 2016). Incorporating bio-filters in the composters, could be beneficial in deodorizing the site by reducing the gaseous emissions and overcoming the problem of pollution (Onwosi et al., 2017; Pagans, Font, et al., 2006).

2.4.3 Generation of leachate

Composting ensures nutrient rich product that is effectively used in agricultural, horticulture and other related services and also provide us with a clean and healthy environment. During the process due to loading of the organic waste, moisture, precipitation and biochemical reactions in the compost pile, generation of leachate takes place. The leachate produced is generally a yellow to dark brown colored liquid that attains color due to the presence of organic matter and suspended and dissolved salts (Onwosi et al., 2017). The most important factor regulating the quantity and quality of leachate generated is the composition of feedstock, that varies with season, due to which the water content in the substrate is also not constant (Roy et al., 2018). The quantity of waste added and temperature also affect the production of leachate which is a potent by-product in composting (Colón et al., 2010; Onwosi et al., 2017). Generation of leachate and its management is a matter of concern, because it comprises of organic and inorganic matter, particulate matter, heavy metal contamination and other toxic elements, which can disturb the surrounding, affect the health and quality of environment and cause degradation of land. Also, if the nitrogen content in the raw material is high, the amount of ammonium ion (NH_4^+) in the leachate will increase along with high volatization rate of ammonia in the heap of waste being composted. Therefore, it is important to analyze the other physical and chemical parameters of the leachate generated, before taking it into usage.

2.5 Circular Economy and Composting

The treatment option available for the management of waste, in most of the developing countries, is its disposal in sanitary landfills or open dump sites (Al-Khatib et al., 2010; Ferronato et al., 2019). The current municipal solid waste management practice follows a linear model that revolves around the concept of take, make and dispose concept, which has become a global challenge and issue of concern environmentally, socially and economically. To preserve the product quality and to bring the material wasted during the extraction of raw material, manufacturing, packaging and consumption, back into the system for a sustainable living, there is a need to shift from the linear model to the circular model of economy.

The circular economy is an idea following the zero-waste policy, to circulate the available resources, reusing and restoring, and minimize the waste generated in any form of leakage or disposal, by closing down the materials loop (Rashid & Shahzad, 2021). The main aim of the CE model is the reduction in the use of virgin raw materials and to increase the life of a product and longevity which is equal to its limitlessness (Ferronato et al., 2019; Franklin-Johnson et al., 2016; Paes et al., 2019). Environment, society and economy, are the three important pillars of waste management which will be positively affected by the integration of solid waste management to circular economy (Geng et al., 2010; Paes et al., 2019). The contribution of organic waste is approximately 44% of the total waste generated globally, management of which could help help in reducing burden over land (Babu et al., 2021). According to the action plan for CE proposed by the countries in the European Union, there will be reduction in the food waste generated by 50% per capita, at the consumer level in the value and supply chains, by the year 2030 (Rashid & Shahzad, 2021).

The circular bio-economy is the exploitation of resources in a sustainable and cost-effective manner, which are renewable, producing valuable products that are biologically efficient such as bio-fertilizers (compost) and energy from the gaseous emissions during the treatment of waste. The CE model can be implemented by composting, which is the most effective method of treatment of organic waste, contributing in closing the waste-energy-food loop, where production of compost and savings in terms of money and material, are the two primary objectives (Rashid & Shahzad, 2021). Circular economy preserves the value of the product by reclaiming the raw materials and feedstock from the waste which can be used to recover resources in a sustainable manner, introducing the concept of urban mining.

Urban mining is an idea to deal with the issue of waste management globally, but in a regulated manner, as it may be problematic to the health of the miners if done incautiously. The waste-pickers belong to the vulnerable group of the society including women, children and physically disabled, as they face negligence and social stigma, while working under unhygienic conditions of the waste collection site. Urban mining through composting would help to mitigate land degradation problems by not allowing the urban waste to get diverted to the landfills, by treating the organic waste through biodegradation process and inorganic waste through the process of recycling. The concept of urban mining contributes in the circular economic model of management of waste and improving the quality of environment and health with the economic and social growth of the developing countries.

2.6 Economic Aspect of Circular Economy and Employment Generation

Biodegradation of organic waste results in lower bulk density, around 600-700kg/m3, due to significant reduction in weight and volume, which is the result of mineralization and volatization of organic acids thus, reducing the cost of transportation of the waste material (Babu, Prieto Veramendi and Rene, 2021). Composting of municipal solid organic waste avoids landfilling, therefore, the cost incurred in the disposal and transportation to the landfill site is also reduced. Transportation cost is also included during the collection and segregation process, which can also be avoided if the organic and inorganic fraction of the waste is segregated at source. The environmental savings also depend on the production of methane gas in the form of carbon credits, in the countries where carbon credit trading is functional, by calculating the potential of methane emissions, generating revenue and contributing to the total income of a nation (Rashid & Shahzad, 2021). Conventionally, the source of nutrient for the crops produced in agriculture are the synthetic fertilizers manufactured in the industries.

Composting helps to save on the production and consumption of the synthetic fertilizers, by the manufacturers and the farmers respectively, as the essential nutrients are administered to the soil naturally through the application of compost as an organic fertilizer, which can also be sold to the market by the farmers to facilitate in the income of the farmers. The compost as an amendment, revitalizes the soil, which produces better quality products in the form of food and fiber, to be sold in the market at a higher market value. Better product quality promotes better health of the workers, so, the working labor hours and treatment efficiency of the waste is also improved, consequently, adding on the GDP of a nation.

Circular economy not only deals with the minimization of waste, but also supports to fulfill the goals of sustainability and issues related to climate change. Composting helps in reduction of the emissions of methane gas which is a major contributor in the climate change phenomenon.

From the start of the economic cycle, till closing the loop, there is a need of people's participation in different areas of service. The organic waste consists of a major portion of disease-causing pathogens, which affect the health of the people residing nearby the dumping site. The odor released during the decomposition of organic waste and burning of the debris creates nuisance to the environment and society residing nearby (Ferronato and Torretta, 2019). The ecological sanitation and reduced emissions, help in resolving the problem of environmental contamination (air, land and water) and human health. Improved health would lead to reduction in the cost of treatment of the people including the workers and local residents, which will allow them to contribute more hours of service which will again improve the GDP. The growth in the economy would provide a platform for technological advancement for better treatment and management of waste, increased efficiency and reduced emissions, ultimately improving the overall environmental quality.

The processes involved in the production of compost from its collection till formation of the final product require service providers, for the purpose of operation and maintenance of the composter which will generate employment in both formal and informal sectors. The informal section of the workers in the field of waste management are particularly the rag pickers (ecological operators), being portrayed negatively and given less importance, contributing majorly in the waste segregation and recycling process (Ferronato et al., 2019; Wilson et al., 2009). The CE model demands the incorporation of the informal sector in the formal waste management process, giving equal rights and adequate financial support to resolve the issue of unemployment and poverty in the developing countries (Ferronato et al., 2019).

2.7 Involvement of the Stakeholders in Management of Municipal Solid Waste

The local communities play a vital role in handling the sustainable chain of urban waste management and contribute their part in the socio-economic development by improving the environmental quality to meet the requirements of the future generation which relies on today's participation. The stakeholders involved in the municipal solid waste collection and treatment process are the households, private sector, municipality and the informal sector. The role of the households would help in source segregation of organic and inorganic fraction of solid waste and assist in the curbside collection system in the urban and suburban areas, to reduce the burden over the agencies and institutions involved in the collection of waste. The people's participation would help in improving the sanitary state of the localities, keeping the streets clean and disease-free, keeping in mind the health and safety of the inhabitants and local species of flora and fauna.

The private sector involved would help in treatment of waste consisting different fractions of biodegradable, non-biodegradable, recyclable, reusable and toxic materials. Introduction of new markets in the area would give ample opportunities for trade and commerce and support the economic growth, improving per capita income and development of the nation. The municipalities play an important role by providing reliable data about the activities and methods involved in the solid waste management practice, involving citizens and spreading public awareness about the same.

The public sector also helps to reduce the cost of transportation and disposal of waste, managing the landfills in a sustainable manner to enhance the environmental quality and also improving the rate of recycling. The informal sector (waste pickers) can get incentives, sanitary insurance and other expenses from the government, to live their life in an organized manner, being accepted by the society to work with other organizations/institutes, collaborating together for the overall growth of the developing countries environmentally, socially and economically (Ferronato et al., 2019).

2.8 Global Initiatives on Circular Economy Model

The concept of circular economy has begun to be followed and implemented worldwide, with an idea to promote the sustainable management and treatment of waste produced from any sector or industry. However, the concept has been formulated locally without implementing the policies on a large scale. Due to the lack of awareness and resources, several regions/countries are unable to fulfill the need of the model properly. There is a need of extensive research over the concept of circularity so that it could be spread in the areas lagging behind. However, there are some areas, where the private and government organizations have taken a step forward to minimize the waste generated by recycling it and reusing the revamped product as a valuable resource that is economic and environmentally beneficial. The policy and framework of many regions are based on the treatment and management of municipal solid waste, whereas, some of the areas have focused upon the recyclability of e-waste. Thus, countries have streamlined strategies according to their requirement and type of unmanaged waste in their area. Table 2.1 illustrates the policies, directives and initiatives taken by few countries or regions around the globe, with a challenge to combat the waste management crisis in an effective manner.

Table 2.1 Global initiatives on circular economy

Country/Region	Year	Initiative	Ecological and Economic benefits	Reference
Kingdom of Saudi Arabia(Gulf country)	2020	• Around 76% of methane gas is emitted from landfills in the country. A policy framework was launched, called vision 2030 incorporating the circular economy model. • Organic food waste was converted to compost, without diverting to the landfills, in the city of Makkah with the assessment of the environmental and economic benefits.	• Reduction in the production of CH_4 could have been 0.043 Mt through composting from OWF in 2015. • In the year 2015, the kingdom could have saved an amount of 524 MSAR and 617 MSAR as a dumping fee and environmental saving respectively. • The savings are projected to rise to 914 MSAR from the dumping fee and 1078 MSAR as a total environmental saving, by the year 2030.	(Vision-2030, 2020), (Rashid and Shahzad, 2021)
	2020	• The target for recycling municipal waste is set to 60% by 2030, under the Circular Economy Package, including the process of composting and anaerobic digestion, as the percentage contribution of bio-waste is nearly 34%.	• Reduction in the cost of purchasing synthetic fertilizer as it was replaced by natural fertilizer (compost), to reduce the disposal of waste and recover materials to reuse and recycle.	(Torrijos, Calvo Dopico and Soto, 2021) , (Ferronato et al., 2019)

European Union	2014	• EU developed a research program dealing with sustainable innovations and development, Horizon 2020. • The EU adopted Directive 2008/98/EC in association with the European Commission (EC), for the improvement of the waste treatment facilities/activities, keeping in mind the health of the people. • Directive 1999/31/EC on landfilling.	• The recycling rates for MSW and packaging waste increased by 13% in the year 2004-14 and 10% in the year 2005-13 respectively. • 43% of MSW was recycled in Norway in the year 2014. • Recovery of 65% of packaging waste was accomplished in the year 2013.	(Ferronato et al., 2019)
India (Pune)	2016	A detailed action plan was prepared by The World Institute of Sustainable Energy (WISE), an NGO, for the management and treatment of urban e-waste.	The goal was to devise a strategy for capturing 60% of e-waste generated in the next two years, implementing the circular economy system.	(Fiksel, Sanjay and Raman, 2021)
China	2009	The Circular Economy Promotion law was constituted involving policy makers belonging to the local, state and central level.	• The management of solid waste and e-waste in the country showed considerable achievement towards the goal of circular economy. • Policies related to zero waste are also being implemented to encourage the practice.	(Rashid and Shahzad, 2021), (Guo et al., 2017)

	2008	First to implement law abiding circular economy principles and encourage other nations to follow the similar practice.		
	2005	The National Bureau of Statistics of China published development index of the circular economy, comprising of consumption of resources, waste generation, recycling and disposal rate.		
Canada	2006	The Agricultural research innovation sector focused on the Agricultural Bioproducts Innovation initiative.	Encourage the investment in bioproducts, to promote circular economy/bioeconomy and reduce GHG emissions responsible for the climate change phenomenon.	(Priyadarshini and Abhilash, 2020)

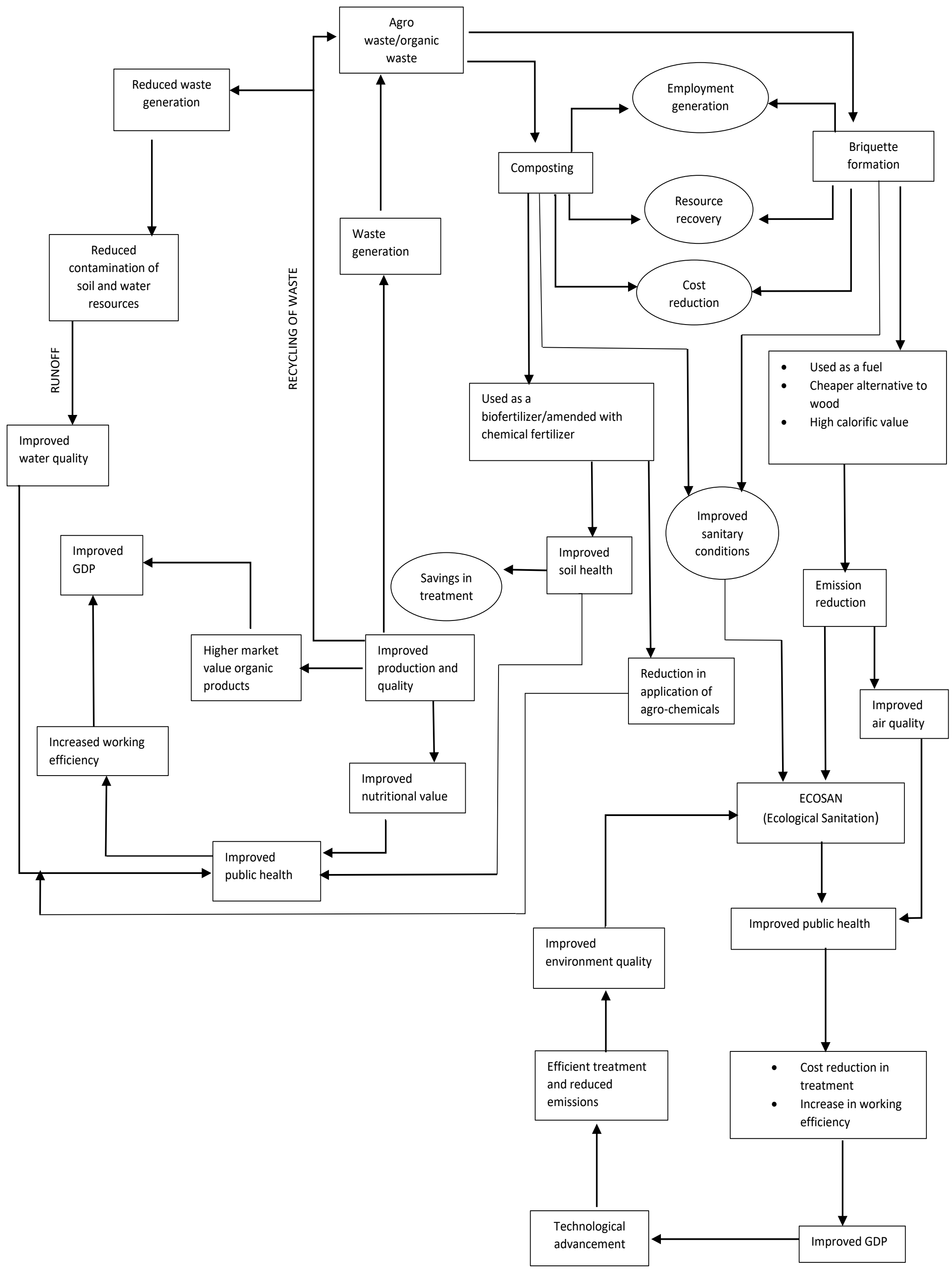


Fig 2.1 Flow chart illustrating circular economy through treatment of organic (agro)

2.9 Research Gap

- Composting of plant biomass or plant based raw material is a time-taking process, as it is made up of lignin that is difficult to degrade. New methods or techniques must be incorporated in the treatment process to enhance the decomposition rate. Moreover, due to low bulk density, the collection, segregation and transportation of the plant waste is comparatively not easy, resulting in involvement of high cost of treatment.

- The method of composting of agriculture waste/plant-based biomass has not been implemented over large scale in the developing countries, residue burning is the most prominent method of agro-waste disposal. There are no policy implementations that incentivize the farmers or promote composting of waste, where they still continue the burning of crop residue which is responsible for the harmful gaseous emissions affecting the overall environmental quality and human health. The plant-based waste is generally stacked up in the field, in the locations situated nearby, is either burnt on-site or allowed to decompose naturally in a gradual manner.

- Management of waste still follows a linear model. A large portion of waste is dumped at landfill sites without initial segregation and processing, this not only burdens the available land but also leads to environmental degradation, social and economic inefficiency. The shift towards circular economy model is a viable solution, to minimize the generation of waste and achieve the goal of zero waste policy.

  There is a void in the research dealing with the concept of circularity as very few countries/regions have taken appropriate measures and initiatives to formulate and adopt the concept of circular economy.

- Lack of awareness among the people regarding the proper management and treatment of solid waste and unorganized work-life, have overlooked the benefits of composting locally without increasing the burden over landfills, and using biofertilizers instead of synthetic ones. This is one of the causes which is affecting the social and environmental health, despite of the formulations in policies of the government to achieve the sustainable goals by the year 2030.

MATERIALS AND METHOD

3.1 Study Area and Collection of Raw Material

The University (DTU) campus includes administrative and academic buildings, library, boys' and girls' hostel, staff offices and residences, sports complex etc. incorporated within an area of nearly 163.87 acres. The data available suggests that the total solid waste generated in the university campus, in the year 2018, was approximately 6274.71 kg/day. Considering the percentage of organic waste generated as 47.4%, the organic fraction of the waste generated in the university was calculated as 2974.21 kg/day, including the yard (agro waste) and foodwaste (DTU, 2018). Composting of organic waste has been observed as a viable solution towards the sustainable management of waste which can also be performed locally, within an institution in smaller treatment units/containers. Thus, the rationale behind the project undertaken was to propose and perform an efficient and economical method to manage the increasing municipal solid waste being generated inside the campus area, simulating with the natural on-site conditions.

The yard waste generally takes approximately 9 months to form a stable compost (Hartz & Giannini, 1998). The raw material can be amended to reduce the time of the composting process. Grab sample of yard waste was collected from different locations in sports ground of the DTU campus. These constituted fresh and dried grass clippings which were then mixed to form a composite sample for composting, and the temporal variations in different parameters involved in the process were studied. The composite mixture was then divided into two portions (inoculated and uninoculated), and the analysis was done on 48th, 128th and 150th day of composting, denoted as D1, D2 and D3, separately for the yard waste with and without inoculum.

Fig 3.1 Collection of raw material from the DTU sports complex

3.2 Temperature Variation

Table 3.1: Variation in temperature with the depth of immersion of the temperature probe

	Depth of immersion of temperature probe (cm)	Temperature (°C)
Fresh heap	7	37.9
	24	48.8
Dry heap	7.5	35.5
	16	36.3
Mixed	15	31.1
	31	46.9

The temperature of the compost pile plays an important role in determining the activity of the microbes and hence, the rate of decomposition of organic matter. The temperature varies with depth as the ambient temperature and the oxygen supply rate (aeration) is not uniform everywhere, at the initial stage. The variation in the temperature was observed at different depths at different locations considering fresh, dry and mixed heap of yard waste/organic waste for the measurement, inside the university campus, with the help of a temperature probe. The temperature varies with depth and is not uniform throughout the pile. This is one of the reasons that turning of the compost pile is done at regular intervals to maintain the uniformity in temperature as well as aeration.

Table 3.1 depicts the change in the degree of temperature with depth, for different lengths of immersion of the probe, which shows that at the deeper sections of the waste pile the temperature is more as compared to the shallow parts, suggesting that the ambient temperature and the oxygen supply (aeration) is non uniform throughout. The temperature of the fresh heap shows major difference than the dry and mixed heaps. This is due to the increased microbial activity that has brought rise in the temperature at various depths. Deeper sections have higher temperature as they are less in contact with the ambient temperature, so the heat inside remains generally unaffected. At deeper sections, the conditions are more favorable for the growth and multiplication of the micro-organisms and perform the process of decomposition of organic matter. The temperature probe was connected to an iron rod, for the measurement at deeper section of the pile of yard waste.

Fig 3.2 Application of temperature probe over fresh heap of the yard waste

Fig 3.3 Application of temperature probe over dry heap of the yard waste

3.3 Moisture Content

Moisture content is another important parameter affecting the growth of the microorganisms responsible for the degradation of the organic matter. The percentage of moisture varies with the structure and composition of a material. Thus, moisture content of some organic waste samples was noted, with the help of the moisture analyzer (Precisa XM 60) in the laboratory (Fig 3.5) Out of the seven samples taken, onion peel and dry leaf showed maximum and minimum percentage of moisture content due to the water holding capacity being more in onion peel than any other sample.

The moisture content of the plant material (fresh grass clippings and dry leaf) is comparatively less than other organic material as the plant biomass has less water holding capacity due to its complex structure. Thus, it requires more moisture content externally, to enhance the decomposition rate during composting. The following bar chart illustrates a comparative analysis of the percentage moisture content in different organic samples including kitchen and yard waste (Fig 3.4).

Fig 3.4 Moisture balance measuring moisture content of a sample of grass clipping

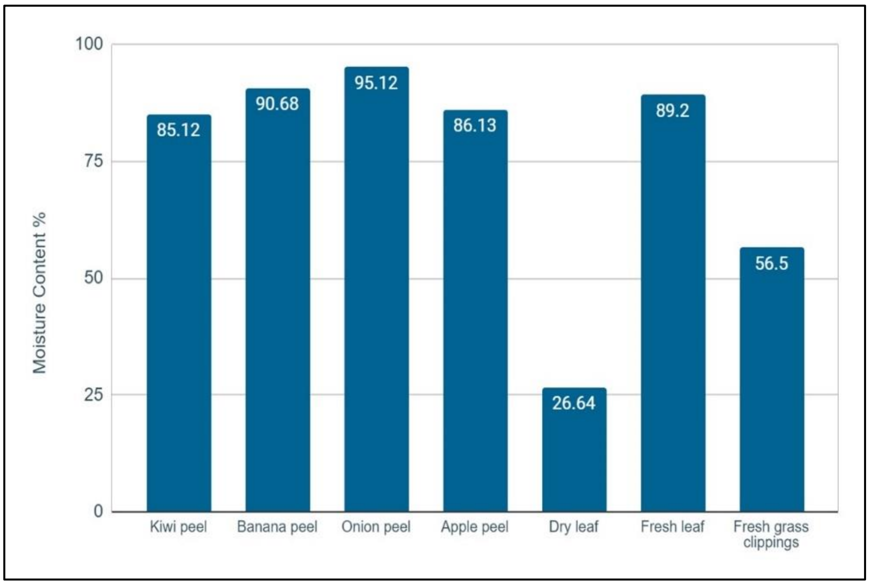


Fig 3.5 Moisture content (%) of different organic samples

3.4 Preparation of Inoculum

Inoculation involves introduction of a microorganism into a suitable environment to promote its growth and to optimize the conditions favorable for efficient microbial decomposition of organic matter during the process of composting. The specie suitable to breakdown the complex lignin-based structure in plant biomass and degrade the organic matter at a faster rate is the white rot fungi (*P. Chrysosporium*), which was introduced to prepare the inoculum in the laboratory with the preparation of the fungal growth medium.

3.4.1 Preparation of growth medium

Potato Dextrose Agar (PDA) was used for the growth of fungi. PDA, in general, is a medium for the growth of yeasts or moulds that can be supplemented with antibiotics to inhibit bacterial growth.

Procedure

1. Mix the following reagents/components, as mentioned in Table 3.2 (composition mentioned per 1 litre of distilled water), in 250ml of distilled water.
2. The pH was maintained approximately at 5.
3. Stir and heat the mixture till it gets dissolved fully, covering the top with a cotton plug tightly.
4. Autoclave the mixture at 121°C for 15-20 minutes at a pressure of 15 psi.
5. Allow the autoclaved mixture to cool preventing it from getting solidified.

Table 3.2 Composition of PDA

COMPONENT	CONCENTRATION (g/l)
Peptone	2.50
Dextrose	5.00
Potassium phosphate	1.25
Magnesium sulphate	0.50
Rose Bengal	0.50
Streptomycin	0.10
Agar	10.00

3.4.2 Pouring, plating and monitoring of growth

Procedure

1. Take the flask to the laminar air flow chamber for the process of sterilization and plating.
2. Remove the cotton plug gently and add Rose Bengal and Streptomycin to the mixture, where the color changes from pale yellow to pink.
3. Take the sample and transfer it to the petri dishes. Allow it to solidify in a laminar air flow chamber.
4. After solidification, inoculate the dishes with microorganisms (white rot fungi).

5. Place the petri dishes in the incubator at room temperature and monitor regularly for the growth of the fungi.
6. After 3 days of incubation, observe the growth of hyphae over the growth media. (Rose Bengal was added as a supplement, which controls the excess fungal growth, in addition to streptomycin which is an antibiotic that inhibits the bacterial growth)
7. After the hyphae achieved its maximum growth, take a part of hyphae and keep it under microbial examination.

The inoculum was finally prepared by diluting the PDA consisting white rot fungi with the addition of some amount of jaggery, DAP (diammonium phosphate) and curd as they contain vital nutrients such as calcium, magnesium, potassium and ammonium phosphate suitable for the nourishment and rejuvenation of soil to enhance its fertility.

(a) (b)

Fig 3.6 Petri dishes inside the incubator for fungal growth (a); Pre-cultured white rot fungi (b)

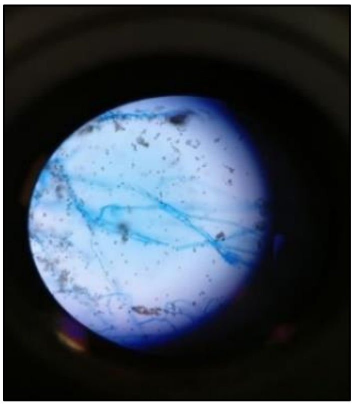


Fig 3.7 Microscopic view of white rot fungi (magnification of 10x)

3.5 Composting of the Raw Material

The composite mixture of the yard waste was divided into two halves, sample 1 and sample 2, each weighing 8.2kg, kept in two partially closed containers. Sample 1 was composted with the addition of inoculum whereas sample 2 was composted without inoculum. Although, the inoculum was added from outside, but due to the external operators occurring naturally, the process is affected by them when kept in an open environment. The experiment was carried out to analyze the physical and chemical characteristics of the compost in the initial 4-5 months of composting (Dec 2021-May 2022). The requirement for the aeration (oxygen supply) was fulfilled by the partial covering of the containers where, regular turning of the waste samples was done frequently, in the interval 3 to 4 weeks. Figure 3.9 represents the two portions of the yard waste (with and without inoculum), prepared for the small-scale aerobic composting within the campus area.

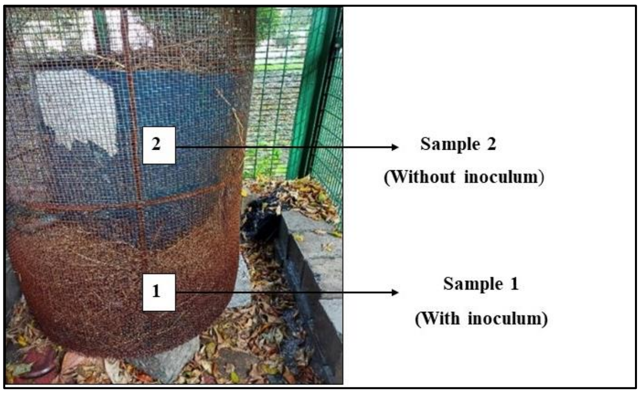


Fig 3.8 Arrangement of composting bins

The plant biomass contains less moisture as compared to the other organic wastes (such as kitchen waste). The moisture for manually added, at regular intervals, and was tried to be in the optimum range of moisture content i.e., 40-60%, preventing the sample from drying completely, as it may restrict the growth of the microorganisms, and decrease the rate of decomposition. Figure 3.10 and 3.11 shows the addition of moisture in the raw material and turning of the pile, respectively.

Due to the adverse climatic conditions and rise in the temperature the frequency of the application of the moisture was increased in the month of April-May to retain the optimum moisture content required for the compost. However, the effect of ambient temperature also played a role in the moisture holding capacity of the compost pile.

Additionally, jute bags were used to cover the pile maintain the temperature of the container to avoid excess drying of the plant based raw material.

Composting is not complete without the release of specific gases, and it is never odorless. The release of ammonia and sulphur is more prominent in the process which could be problematic locally. Organic materials containing odorous molecules would contribute more to pollution in the environment. The stench created could have poor health effects and cause respiratory difficulties to the locals in the vicinity, lowering quality of life. Therefore, the assembly was kept in an open area/environment to avoid odor nuisance due to the release of gaseous emissions during the process of composting.

(a) (b)

Fig 3.9 Application of moisture (a); Turning of the pile (b)

3.6 Measurement of Physical and Chemical Parameters of Collected Raw Material

3.6.1 Chemical Properties

a) pH

pH is a key element in regulating the rate of degradation because it promotes the activity of microorganisms responsible for organic matter decomposition. For optimal microbial activity, the pH value indicated is nearly in the range of 5.5 to 8 (Chen et al., 2015; Onwosi et al., 2017). The pH was measured in the laboratory using the pH meter (multi-parameter kit), after making a suspension of the samples in 1:10 ratio.

Fig 3.10 HACH make HQ 40-D Multi-parameter meter kit.

b) Ash Content

The inorganic residue left after total incineration or complete oxidation of organic materials in a food sample is referred to as ash. It is determined from loss of weight occurring from complete oxidation at high temperature through combustion and volatisation of organic matter. The ash level of a product is determined via proximate analysis for the evaluation of nutrition in the compost which is a key quality attribute (Ismail, 2017). During the composting process the percentage of ash content increases as the oxidation of organic matter (yard waste) takes place due to the microbial decomposition.

c) Fixed Carbon content

Carbon is the direct measurement of organic matter present in the raw material being composted. The carbon content decreases during composting due to the volatization of organic compound as carbon serves as an energy unit for the microbes for the degradation of organic matter.

d) Volatile Organic Compound (VOC)

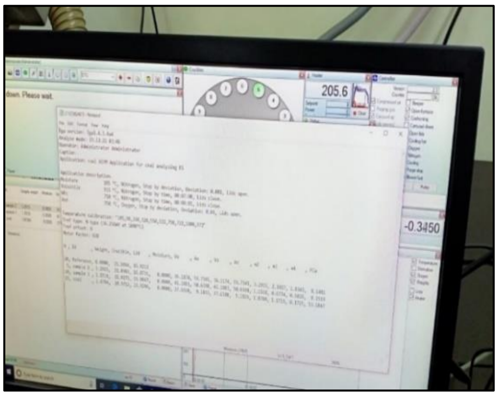
Volatile matter is released when the organic or inorganic fraction of the solid waste experience thermal cracking at high temperature. The volatile organic compounds, which includes alkanes, aromatic hydrocarbon, trimethyl benzene and terpene (in plants), decreases during the process of composting with the increase in mineralization of organic compounds.

The quantitative analysis/ proximate analysis of the ash content (b), fixed carbon content (c) and volatile organic compounds (d) was performed using Thermogravimetric Analyzer (TGA).

Procedure for the analysis

1. The pressure of the gases used in the analyzer (NO_2 and O_2) is set to 2bar each.
2. The thermogravimetric analyzer works automatically beginning with the tearing of the crucibles.
3. After all the crucibles are teared, the lid of the analyzer opens up and the samples are loaded into the crucibles and weighed automatically.
4. The analyzer heats up the furnace to the specified temperatures required to measure ash content (up to 750° C), VOCs (up to $915\ ^{\circ}$ C) and carbon content (up to 750° C). The respective temperatures are maintained till all the constituents are completely read by the analyzer.
5. After the completion of the process, the final readings are automatically generated and is shown on the popped-up window on the desktop (Fig 3.13).
6. The furnace is allowed to cool down by switching on the blower attached to the analyzer and the samples are taken out containing ash as residue.

Fig 3.11 The automatic thermogravimetric analyser (ELTRA THERMOSTEP)



(a) (b)

Fig 3.12 Output window for proximate analysis (a);
Residue remaining after the analysis (b)

e) Nitrogen

The organic nitrogen is mineralized and released as soluble NH_4^+ ions. The ammonium ions are removed by volatization of ammonia (NH_3(g)), adsorption by plants, immobilization by the micro-organisms, leaching/runoff and nitrification. However, the mineralization of organic nitrogen depends on the C/N ratio, temperature and moisture content. According to a study, there was not much difference between the measured value of nitrogen in the Kjeldahl digestion method and other modified methods in fresh manures to find the total nitrogen content, to find out the C/N ratio. (Mahimairaja et al., 1990).

Procedure for analysis

The experiment for the Total Kjeldahl Nitrogen (TKN) is performed in following three steps:

Step 1 Digestion

Digestion is the first step in the calculation of TKN to break down the bonds that hold the polypeptides together and convert them to simpler chemical compounds such as water, CO_2 and NH_3.

1. Take 0.5 g sample of solid waste.
2. Add 10ml concentrated H_2SO_4 solution with 3g catalyst mixture in the ratio 10:1 (10 parts of potassium sulphate and 1 part of cupric sulphate) and keep the mixture in the digestion tube.

3. Leave the mixture to boil in the digestion chamber for 3 hours till the mixture gets completely digested.
4. Allow the mixture to cool down for distillation.

Fig 3.13 Digestion chamber for the analysis of TKN

Step 2 Distillation

The purpose of distillation is to separate ammonia from the digestion mixture.

1. Take the tube containing the mixture used in the digestion chamber and fix it into the distillation chamber containing reagents i.e., NaOH and H_3BO_3 to perform distillation.
2. Take a conical flask and add 3 drops of bromocresol and 5 drops of methyl red as an indicator, and allow the distilled solution to get collected into the flask, after 10 min of the distillation cycle.

Fig 3.14 Distillation assembly for TKN analysis

Step 3 Titration

1. Remove the conical flask from the distillation chamber and titrate with 0.1 N HCL.
2. Initially the sample is dark blue in color which turns red after the end point is achieved during the titration.

Fig 3.15 Titration for analysis of TKN

Calculation

The total kjeldahl nitrogen is calculated by the following equation (2):

$$\%N = \frac{1.4 * V * N}{W} \quad (2)$$

where,

%N = percentage of nitrogen present in the solid waste sample

W= weight of sample (g)

V= Volume of acid used in titration (ml)

N = Normality of standard acid

3.6.2 Physical Parameters

a) Temperature and Moisture Content

3.2 and 3.3 briefly explains the measurement of temperature and moisture content at the initial stage, as they are the two primary factors that regulate the composting process and the microbial activity.

b) Color

Color is an indicator of compost stability. A gradual darkening can be observed as the raw material undergoes the process of composting. Compost is about to get ready/finished when it starts to become rich and earth like textured and colored (dark brown).

3.7 Cost Benefit Analysis of Bio-fertilizer (compost)

Compost is less expensive than chemical fertilizers, when the cost of production and utilization is considered. Fertilizers are needed more frequently in low-fertility soils, which raise the cost of agricultural products. The compost can be produced naturally and domestically whereas the chemical fertilizers may involve trade investments of chemicals used. The quantity of compost used, per area of cultivation, is more than the synthetic fertilizer used in the same area, but the cost of production of compost is less than any chemical fertilizer, making compost a viable and sustainable treatment method.

Table 3.3 gives an idea about the economic benefit of using compost as a fertilizer rather than switching to synthetic fertilizers. A cost-benefit analysis was done considering all the components given below, using the quantity of yard waste used to produce compost in the project area. The analysis was done for the complete process of production of crop from the process of tilling the field till the harvesting of the crop.

Calculation

The units and cost of production in the table given below, were modified as per the weight of the raw material taken into consideration, i.e., 8.2 kg.

The cost incurred in the process was calculated according to 1ton (1000kg) of compost.

Considering linear relationship of cost with all the other factors:

a. Modified cost will be equal to cost/121.95.
b. The units will change accordingly by 0.122%

Table 3.3 Comparison of cost of production by using chemical fertilizer and compost

Component	Units	Cost incurred using Chemical fertilizers (₹)	Cost incurred using compost as a biofertilizer (₹)
Tilling	Twice per crop	2000	2000
Seeding	25kg/hectare * avg seed price	3750	3750
Sowing	4 days of labor	3500	3500
Application of fertilizer	150kg of NPK fertilizer/ 1ton of compost along with 50% subsidy	3750	1250
Removing weeds	4 labor days	2000	2000
Cleaning and Harvesting	8 labor days	4000	4000
Miscellaneous	Transport, monitoring for pest etc	6000	6000
Total		25000	22500

*Source: (Mukunth, 2020)

RESULTS AND DISCUSSION

4.1 General Observation

The physical and chemical characteristics of the compost were analyzed for five months starting from the month of December to the month of May. The analysis was done in the intervals of around 45-55 days and the days of analyses are denoted as D0, D1, D2 and D3, where D0 denotes first day of analysis and D1, D2 and D3 denotes 48^{th}, 128^{th} and 150^{th} days of analysis respectively. The analysis was mainly done after the raw material started to show some positive sign of decomposition physically, i.e., on D1 (day 48), D2 (day 128) and D3 (day 150). The plant raw material i.e., the yard waste contains lignocellulosic compound which takes longer time to decompose than the other organic materials (kitchen waste). The delay in compost preparation is also due to the excessive heat that is a result of climate change, which causes a drop in the rate of decomposition since it takes more moisture to avoid premature drying of the plant-based raw material. The results of different physical and chemical parameters involved in the process of composting are discussed below.

4.2 Effect of Temperature

The temperature of the compost pile plays an important role in the microbial decomposition of organic matter. It was observed that the temperature was quite high in the very beginning and it showed a declining profile from Day 11. The reason for the high temperature value could be the collection of yard waste from the deeper sections of the pile, from the collection site, where the process of decomposition of organic matter might have just begun. Initial temperature for the inoculated yard waste was measured to be 36.6° C whereas that of uninoculated yard waste was measured to be 32.1° C. This rise in temperature of the pile signifies the initial heat energy generated due to the metabolism of the microorganisms (fungi and bacteria) in the initial mesophilic stage. The temperature of the pile starts to decline due to the ambient temperature and dry weather conditions, that slowed down the degradation process. The temperature began to rise again with the change in the weather conditions as the pile captured the heat and moisture more effectively. The mesophilic temperature range (25° C-40° C) is clearly visible between Day 101 to Day 142, where the easily degradable proteins and sugars are broken down. According to the observation (Fig 4.1) the maximum value of the thermophilic temperature has not yet achieved, but the thermophiles have started acting upon the plant biomass, as the thermophilic temperature lies between 35˚ C and 65˚ C.

4.2.1 Effect of ambient temperature on temperature of compost pile

At various ambient temperatures, the components of heat generation, solar radiation and heat lost by radiation, evaporation, convection, and conduction were the key portions of heat balance. The temperature of the pile presented linear relation to the ambient temperature. The air flow also affects the temperature of the pile as if the rate of air flow increased the portion in contact would be cooler as compared to that of the portion away from the flow (Khater El Sayed, 2016). Fig 4.1 describes meteorological trend of temperature from the month of December 2021 to May 2022, where T1, T11, T21, T38, T52, T67, T84, T101, T128, T134, T142, T145 and T150 denotes the time, in days for the temperature measurement after 11^{th}, 21^{st} ,38^{th}, 52^{nd}, 67^{th} 84^{th} ,101^{st} ,128^{th} ,134^{th} ,142^{nd} ,145^{th} and 150^{th} day of composting. The ambient temperature at the initial stage of the process of composting was around 23˚ C. The pile temperature increased with increasing ambient temperature and decreased with increasing airflow rates, with the pile temperature increasing from 36.6˚ C to 37.8˚ C for the inoculated yard waste and 32.1˚ C to 35.5˚ C for the uninoculated yard waste, as the ambient temperature increased from 23˚ C to 42˚ C. The maximum temperature reached, in the analysis period for the inoculated and uninoculated yard waste was 39.4˚ C and 36.2˚ C respectively, when the ambient temperature for around 45˚ C.

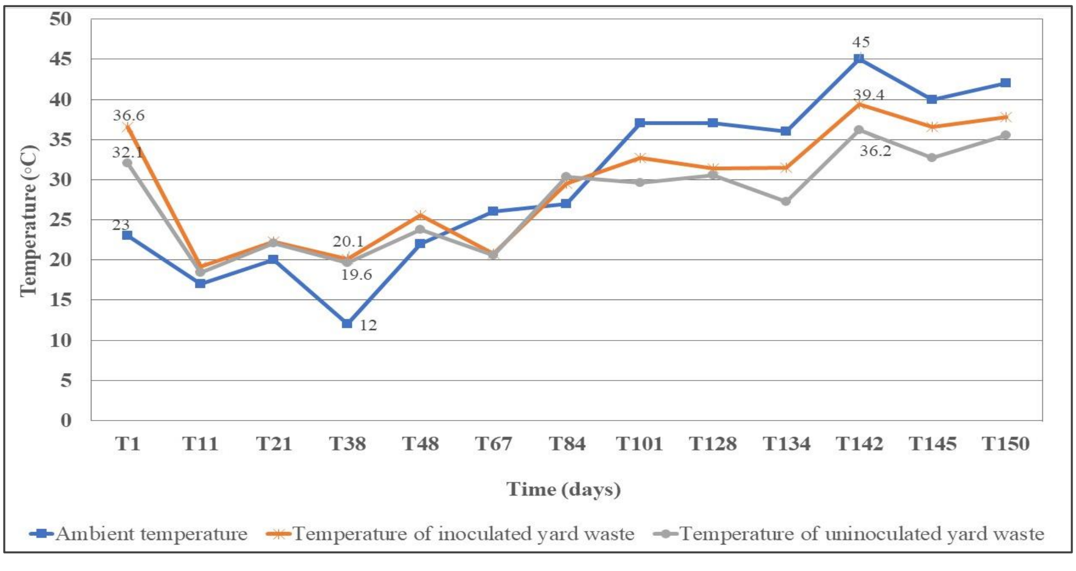


Fig 4.1 Comparative analysis of the temperature of the compost pile

4.3 Change in Color and Reduction in Volume of Plant Biomass

The color of the compost pile changed with time from fresh green to light brown in period of 5 months. Some portions of the pile which were directly exposed to the ambient temperature, the change in color was partial whereas the unexposed portion was found to be darker. The change in the color of the sample of the plant based raw material (inoculated) could be observed in Fig 4.2.

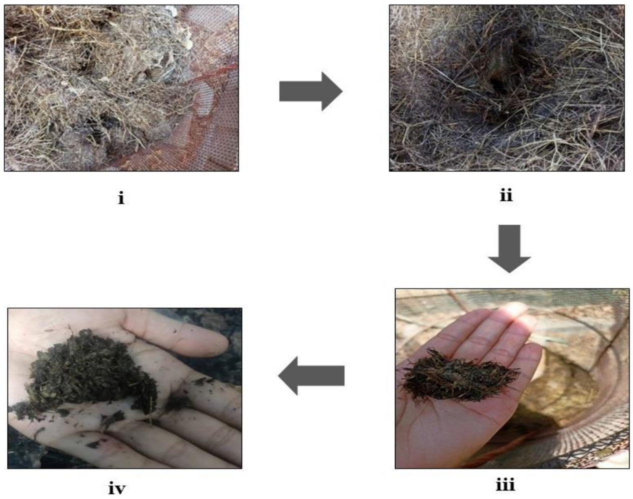
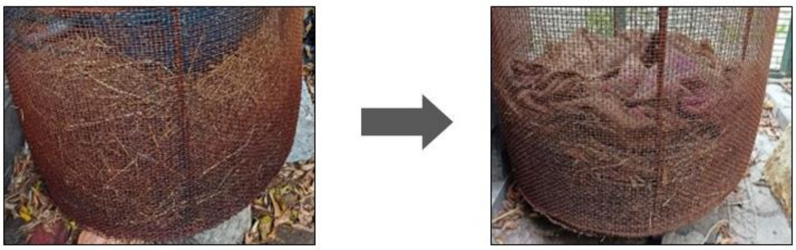


Fig 4.2 Change in color of the composted raw material with time (days)

Composting destroys weed seeds and disease-causing pathogens while also reducing the volume of manure. The volume of the collected yard waste reduced with time due to volatization of organic acids and mineralization of organic nitrogen to ammonia. Due to the decrease in volume and the increase in composted material breakdown, bulk density rose over time during the composting process. In Fig 4.3, it can be observed that there is a reduction in volume and increase in the bulk density by a significant amount in 128 days.



(a) **(b)**

Fig 4.3 Image representing initial volume of the yard waste on day 1 (a) ; Reduction in the volume of the composted yard waste on Day 128 (b)

4.4 pH

The pH in the initial stages of composting was 6.4, i.e., the suspension of the yard waste sample was found to be acidic. This is because, when the bacteria and fungi digest/decompose organic matter, they release organic acids which get accumulated initially. The acidic conditions encourage the growth of fungus and other microbes that feed on organic materials and speed up the decomposition process.

With time the pH increases and the solution becomes alkaline due to the mineralization of organic nitrogen compounds leading to release of ammonia and volatisation of CO_2 due to oxidation of organic matter. The ideal pH value for microbial activity is nearly in the range of 5.5 to 8 for effective microbial activity which is evident from the Fig 4.4 also, that the pH is in the optimum range.

The pH for the inoculated yard waste increased from approximately 6.40 to 7.31, whereas the value of pH for the uninoculated yard waste varied from nearly 6.40 to 7.15 for the duration, considered for the analysis of composting of the yard waste. Fig 4.4 shows the change in pH in the inoculated and uninoculated fraction of the yard waste from Day 1 till the last day of analysis, i.e., Day 150.

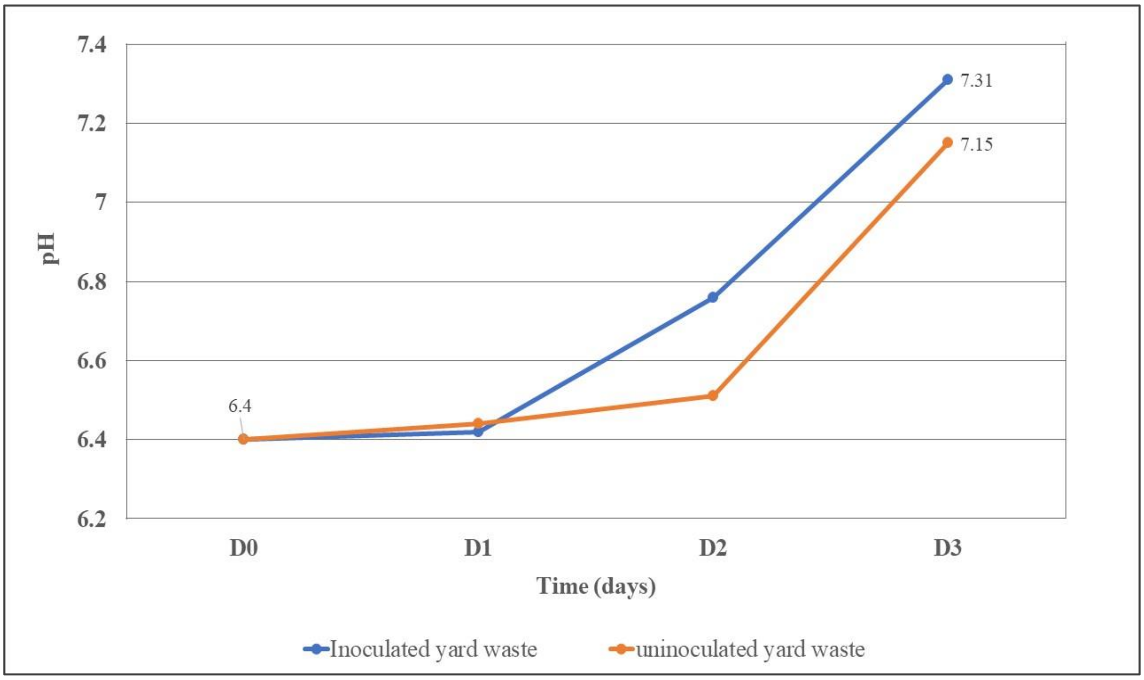


Fig 4.4 Change in value of pH during composting of yard waste

4.5 Moisture content

The moisture content within the analysis period have been mentioned in Table 4.1.
At the beginning of the process, the percentage moisture content observed was 32.02 % for both the samples before inoculation on Day 0. Later, the moisture content was maintained between 30-60% approximately. Increased moisture content limits gas diffusion, lowering open air spaces and resulting in anaerobic conditions, affecting oxygen intake and enzymatic rate. By the 84th day, visible decline in the moisture content of the compost pile has been observed. Very low moisture content values during composting resulted in early dryness, which delayed the biological process, resulting in physically stable but biologically unstable compost. Due to the drying weather conditions, the frequency of application of moisture was increased. The moisture content was again allowed to be kept within the required range, avoiding further dryness.

Table 4.1 Moisture content (%) measured at different time intervals

Time (days)	Moisture content of inoculated yard waste (%)	Moisture content of uninoculated yard waste (%)
T1	32.02	32.02
T11	56.62	43.51
T38	52.13	47.62
T48	45.96	38.60
T67	30.61	30.42
T84	38.00	22.81
T128	67.20	35.66
T142	54.30	31.67
T150	65.13	46.00

On the 150th day of analysis, the resulting moisture content for the inoculated and uninoculated yard waste was 65.13% and 46.00 % respectively. Higher moisture content, in the range of 60-65 percent, may be noted during the main composting stage, which is after Day 128. At the start of the summer, or dry season, increasing the moisture content to 55 percent to 60 percent could benefit as rate of evaporation during hot and dry weather conditions increase. Evaporation in the uninoculated yard waste is more than inoculated because of the inoculant used. The inoculant itself act as a source of moisture, to help the micro-organisms to proliferate. It can be observed clearly in Fig 4.5 that the uninoculated yard waste is less in moisture content.

The inoculated yard waste was able to retain the moisture more as the rate of decomposition of organic is more in the inoculated fraction than the uninoculated fraction. Thus, the production rate of compost is more in the inoculated waste, decreasing the volume of the raw material composted, thus increasing the water holding capacity. Table 4.1 and Fig 4.5 illustrates the variation the percentage moisture content from Day 1 to Day 150 comparing the values measured for inoculated and uninoculated yard waste.

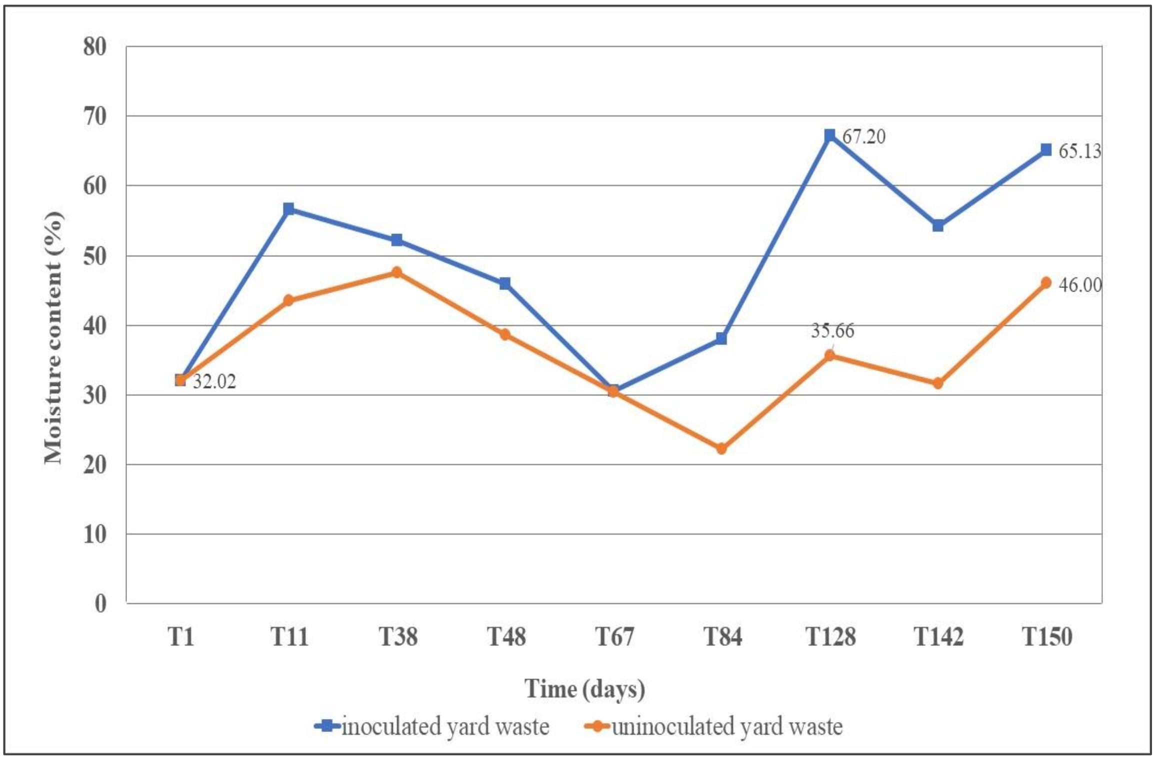


Fig 4.5 Moisture content of the composted yard waste sample

4.6 Results of Proximate Analysis of organic waste (yard waste)

The proximate analysis of the inoculated and uninoculated yard waste was performed on day 0, day 48, day 128 and day 150, to measure the percentage ash content, percentage volatile organic compounds and percentage fixed carbon in the waste sample. Initially, three samples were taken from the composite mixture of the yard waste collected and average of the three was taken into consideration as a result of the analysis on day 1.

The composite mixture was then divided into two portions (inoculated and uninoculated), and the analysis was done on 48th, 128th and 150th day of composting, denoted as D1, D2 and D3, separately for the yard waste with and without inoculum. Table 4.2 shows the result of the proximate analysis, where I1, I2 and I3 are the samples for inoculated yard waste and W1, W2 and W3 are the samples for the uninoculated yard waste against D1, D2 and D3 respectively. The results of the measured carbon content, ash content and volatile organic compounds is discussed in 4.8.1, 4.8.2 and 4.8.3 respectively.

Table 4.2 Result of proximate analysis

Day	Sample	Moisture (%)	Ash content (%)	Volatile organic carbon (VOC) (%)	Fixed carbon (%)
D0	1	31.41	11.47	72.80	15.20
	2	33.29	11.24	62.64	11.27
	3	31.04	10.25	64.03	12.26
Average		32.02	65.85	10.97	12.66
D1	I1	45.96	50.65	41.18	8.15
	W1	38.60	55.73	36.11	8.14
D2	I2	38.00	43.17	46.52	10.30
	W2	22.81	10.33	72.13	17.53
D3	I3	65.13	56.98	36.10	6.91
	W3	46.00	14.41	68.65	16.92

4.6.1 Carbon Content (%)

The carbon content in the beginning of the process was 12.66 % which gradually decreased because of the volatisation of organic carbon due to the decomposition of micro-organisms. There is an increase in the percentage of carbon from the period D1 to D2 which could be seen in Fig 4.6. This rise could be due to the dryness in the weather due to which the rate of decomposition process decreased. Also, there could be a possibility of fixation of atmospheric carbon more as compared to the volatisation of the organic carbon. It can be observed that from D2 to D3, the carbon content begins to decrease again, as a result of increased rate of decomposition. The percentage of carbon at the end of analysis (after 150 days), was found to be 16.92% and 6.91% for the uninoculated and inoculated yard waste respectively. The rate of decomposition in the inoculated yard waste is more than the uninoculated yard waste, hence the volatisation of organic carbon is more in the inoculated yard waste.

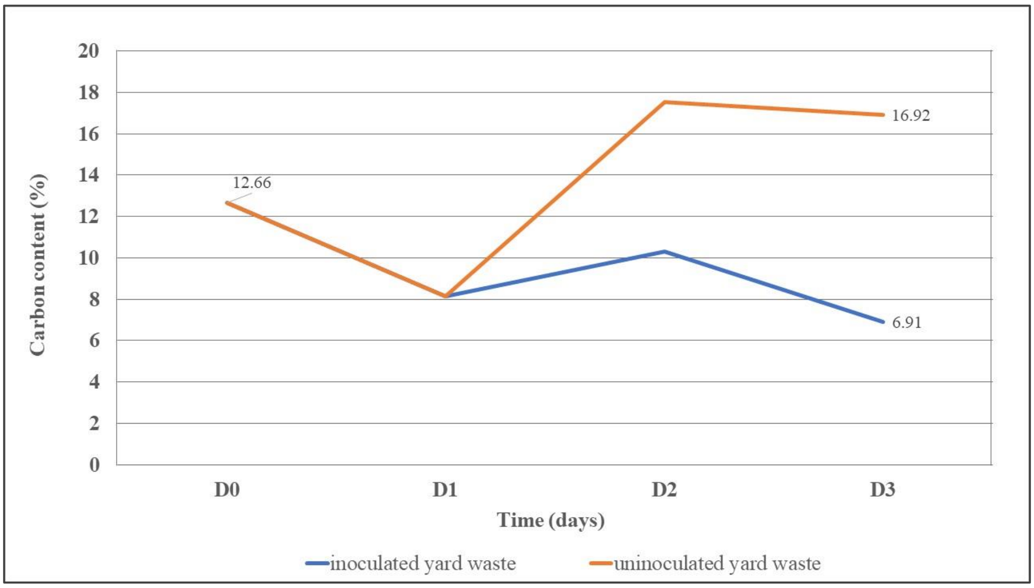


Fig 4.6 Variation in the carbon content (%) during the process of composting

4.6.2 Ash Content

The percentage of ash in the beginning for the plant based raw material was 65.85%.

The ash content decreased between D0 and D2 due to the increase in the percentage of carbon, resulting in less ignition and formation of inorganic residue due to the oxidation of organic matter. The ash content must not be too high in a compost, as it also increases the weight of a compost pile and may also exceed the amount of micro-nutrients present in the ash generated. The ash content decreased more rapidly in the uninoculated waste sample as the decomposition rate was less than the inoculated waste sample because the uninoculated waste was deficient in moisture accompanied by improper aeration, as the uninoculated plant biomass was composted inside a partially closed container, hence received less oxygen supply. The ash content, after the end of analysis, was found to be 56.98% and 14.41% in the inoculated and uninoculated yard waste respectively. Fig 4.7 shows the change in ash content (%) during the process of composting.

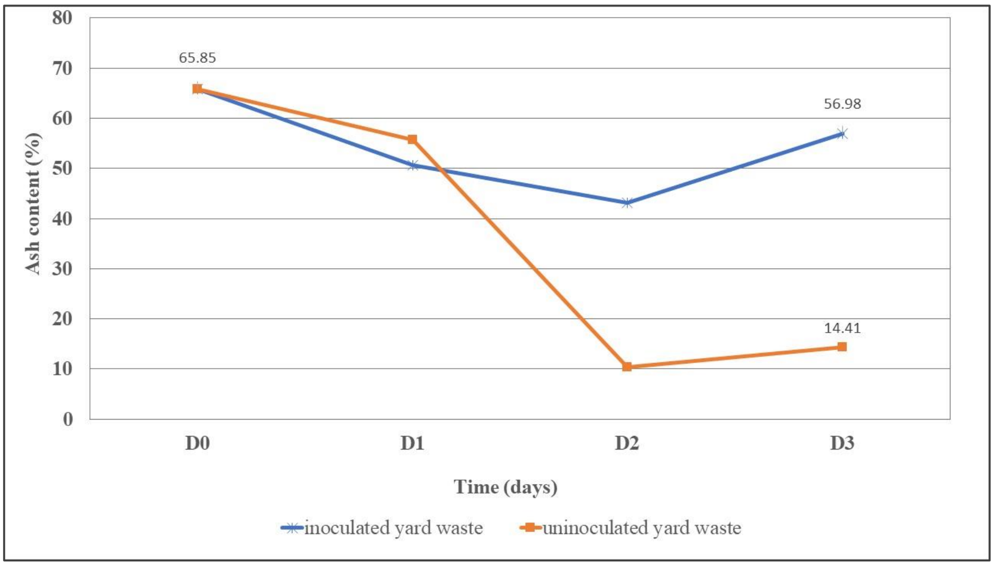


Fig 4.7 Variation in the percentage ash content during composting

4.6.3 Volatile Organic Compounds (VOC)

The volatile organic compounds, in the beginning of the composting process was 10.97% which increased later due to the increase in the percentage carbon content, indicating lower rate of decomposition and creating anaerobic conditions due to improper aeration between D0 to D2, as the VOC formation rate is increased during anaerobic conditions. The VOC, decreased after D2, as a result of increased rate of decomposition. At the end of the period of analysis (after 150 days), the VOCs (%) were found to be 68.65% and 36.10% in the uninoculated and inoculated samples respectively. VOCs decrease with the increase in the temperature, i.e., from mesophilic to thermophilic range. That is why there is early sign of stable compost being made in the inoculated yard waste than in the uninoculated yard waste as the percentage of volatile organic compounds is less in the inoculated plant based raw material. Fig 4.8 illustrates the percentage change in the VOCs produced during composting.

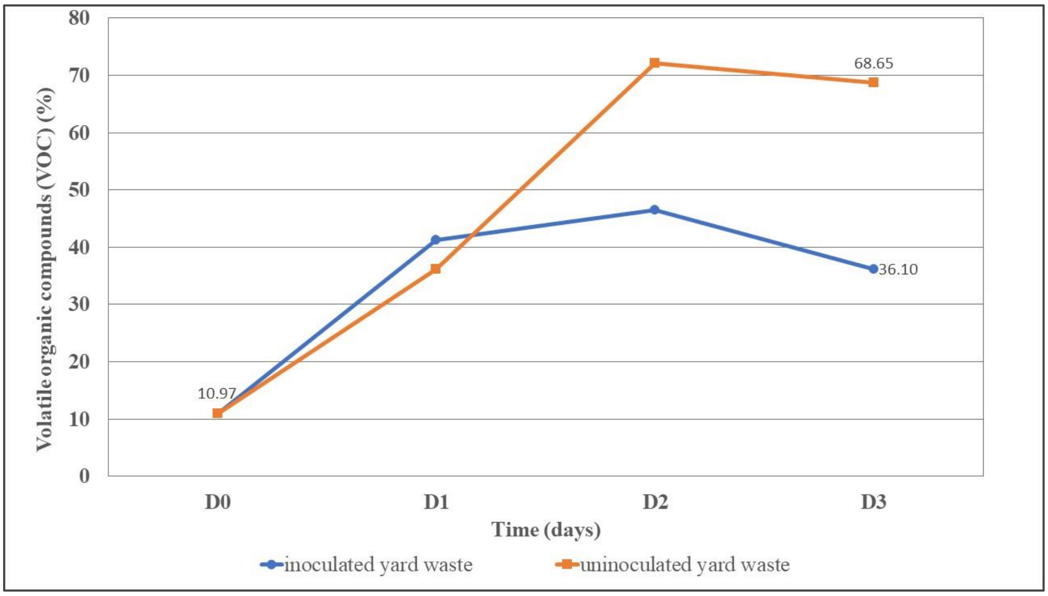


Fig 4.8 Variation in the volatile organic compounds during composting

4.7 C/N ratio

During the composting process, a decrease in the C/N ratio is observed, because the rate of nitrogen mineralization is less than the carbon. The resulting C/N ratio, after the end of the period of analysis, was found to be 18.21 for the inoculated yard waste and 13.73 for the uninoculated yard waste. Formation of ammonia, depends on the temperature and pH. If the temperature is high and the medium is alkaline, the production of ammonia will be more.

From the Fig4.9, it is evident that the C/N ratio follows a decreasing trend. But at the end of the analysis, the value of C/N ratio is found not to be in the optimum range (25-40) for a good quality compost. The temperature in this period of analysis was high and the pH measured was slightly alkaline, as a result of which the formation of ammonia is more. From Fig 4.6 we can observe that there is a decrease in percentage carbon content. Thus, decrease in the carbon content and increase in the amount of ammonia present in the plant biomass, contributed majorly in decreasing the overall C/N ratio. Table 4.3 and Fig 4.9 shows the value and variation in the C/N ratio with time during the process of composting.

Table 4.3 C/N ratios of yard waste during composting

Yard Waste	C/N ratio
I1	28.29
W1	18.72
I2	25.25
W2	14.22
I3	18.21
W3	13.73

I= inoculated; W= uninoculated

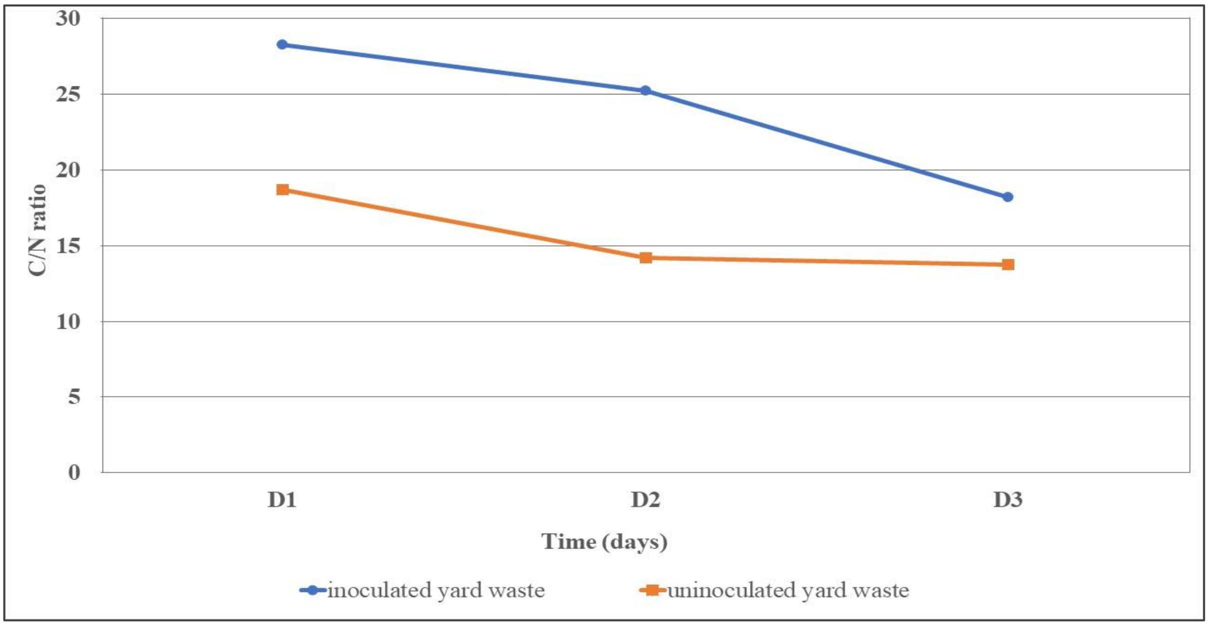


Fig 4.9 Variation in the C/N ratio during the process of composting

4.8 Cost-Benefit Analysis of compost in Comparison with Synthetic Fertilizer

The production cost of the crops has been compared using synthetic fertilizers and compost. From Table 4.4 it can be observed that the cost of tilling of the field, spreading the seeds, sowing, weed removal, harvesting and cleaning and other component, is same in both the cases. The cost incurred in the application of chemical fertilizer and compost differs by a significantly.

The calculated value of the cost of application of 18.3 kg of NPK fertilizer is ₹30.75, whereas the calculated value of the cost incurred in using 8.2kg of compost is ₹10.25 for the same quantity of seeds and area of land i.e., 3.05kg/hectare. The total production cost, including tilling, seeding, sowing, application of fertilizer, harvesting and cleaning, transportation, pest control, labor charges etc., using chemical fertilizer and compost is ₹205 and ₹184.5 respectively. We can observe that there is a difference of ₹20.5 in the cost of production, with a profit of 0.66%, on using compost as an organic fertilizer.

Table 4.4 Comparison cost of production using synthetic and bio-fertilizer

Component	Units	Cost incurred using Chemical fertilizers (₹)	Cost incurred using compost as a biofertilizer (₹)
Tilling	Twice per crop	16.40	16.40
Seeding	3.05kg/hectare* avg seed price	30.75	30.75
Sowing	0.5 days of labor	28.70	28.70
Application of fertilizer	18.3kg of NPK fertilizer/ 8.2kg of compost along with 50% subsidy	30.75	10.25
Removing weeds	0.5 day of labor	16.40	16.40
Cleaning and Harvesting	1 day of labor	32.80	32.80
Miscellaneous	Transport, monitoring for pest etc	49.20	49.20
Total		205	184.5

CONCLUSION

1. Green waste, unlike kitchen trash, has characteristics (such as lignocellulosic structure) that limit its composting ability if proper monitoring is not done. The proportion of materials gathered from different site locations (e.g., leaves, branches, grass, soil), particle size, non-homogeneity, and degree of degradation equally influence these features. The incorporation of the inoculum, prepared from the cultured white rot fungi, contributed in reducing these limits, allowing for proper composting conditions.

2. The inoculated yard waste showed early signs of composting as compared to the uninoculated plant biomass. The thermophilic temperature range (35-65˚C) was observed to occur after 134th day of composting, in the inoculated waste, whereas in the uninoculated waste the temperature began to rise above 35˚C after the 142nd day. From the study and analysis, it can be inferred that there is a delay in peaking of the temperature as compared to the kitchen trash, because of the complex structure of the plant biomass. The rate of degradation of the waste can be increased by the application of inoculum frequently, at regular intervals.

3. The moisture content of the inoculated yard waste was retained for a longer period as compared to the uninoculated waste, as the inoculum also acted as a major source of moisture. On 128th day the moisture content was highest in the inoculated waste (67.2%), whereas it was measured to be only 35.66% on the same day. This accounts for the early decomposition rate in the inoculated yard waste. However, the plant based raw material requires frequent application of moisture, especially during dry weather conditions, due to which the rise in temperature of the compost pile was delayed prominently.

4. The C/N ratio was found to decrease after 128th day due to the increased ammonia production, which is a result of high temperature and alkalinity. Also, the volatisation of carbon was less during this period due to the dryness in weather, which is the result of reduced rate of decomposition of organic matter.

5. Composting justifies the concept of circular economy model of management of waste, as the yard waste was used as a resource to produce compost, without diverting it to the landfills, which is ecologically and economically beneficial. According to the analysis of cost of production of crop, the cost reduced by a significant amount by using the organic fertilizer instead of synthetic fertilizer, for a given specific area. Thus, application of compost on a larger scale could help in reducing the cost incurred in the agricultural practices and the farmers could be incentivized enough, increasing the crop production efficiency.

6. To further evaluate the composting of yard waste with other biodegradable organic materials, field-scale experiments, rather than laboratory and pilot-scale ones, are needed. In addition, a comprehensive set of parameters (e.g., micronutrients, heavy metals, stability, phytotoxicity, and microbiological parameters) must be included to monitor the process and adequately assess the product's stability and maturity.

REFERENCES

Adhikari, B. K., Barrington, S., Martinez, J., & King, S. (2008). Characterization of food waste and bulking agents for composting. *Waste Management*, *28*(5). https://doi.org/10.1016/j.wasman.2007.08.018

Al-Khatib, I. A., Monou, M., Abu Zahra, A. S. F., Shaheen, H. Q., & Kassinos, D. (2010). Solid waste characterization, quantification and management practices in developing countries. A case study: Nablus district - Palestine. *Journal of Environmental Management*, *91*(5). https://doi.org/10.1016/j.jenvman.2010.01.003

Avtar Singh Bimbraw. (2019). Generation and Impact of Crop Residue and its Management. *Current Agriculture Research Journal*, *7*.

Babu, R., Prieto Veramendi, P. M., & Rene, E. R. (2021). Strategies for resource recovery from the organic fraction of municipal solid waste. *Case Studies in Chemical and Environmental Engineering*, *3*. https://doi.org/10.1016/j.cscee.2021.100098

Bergersen, O., Bøen, A. S., & Sørheim, R. (2009). Strategies to reduce short-chain organic acids and synchronously establish high-rate composting in acidic household waste. In *Bioresource Technology* (Vol. 100, Issue 2). https://doi.org/10.1016/j.biortech.2008.06.044

Cerda, A., Artola, A., Font, X., Barrena, R., Gea, T., & Sánchez, A. (2018). Composting of food wastes: Status and challenges. In *Bioresource Technology* (Vol. 248). https://doi.org/10.1016/j.biortech.2017.06.133

Chen, Z., Zhang, S., Wen, Q., & Zheng, J. (2015). Effect of aeration rate on composting of penicillin mycelial dreg. *Journal of Environmental Sciences (China)*, *37*. https://doi.org/10.1016/j.jes.2015.03.020

Cheng, S. Y., Tan, X., Show, P. L., Rambabu, K., Banat, F., Veeramuthu, A., Lau, B. F., Ng, E. P., & Ling, T. C. (2020). Incorporating biowaste into circular bioeconomy: A critical review of current trend and scaling up feasibility. In *Environmental Technology and Innovation* (Vol. 19). https://doi.org/10.1016/j.eti.2020.101034

Chia, W. Y., Chew, K. W., Le, C. F., Lam, S. S., Chee, C. S. C., Ooi, M. S. L., & Show, P. L. (2020). Sustainable utilization of biowaste compost for renewable energy and soil amendments. In *Environmental Pollution* (Vol. 267). https://doi.org/10.1016/j.envpol.2020.115662

Chowdhury, M. A., de Neergaard, A., & Jensen, L. S. (2014). Potential of aeration flow rate and bio-char addition to reduce greenhouse gas and ammonia emissions during manure composting. *Chemosphere*, *97*. https://doi.org/10.1016/j.chemosphere.2013.10.030

Colón, J., Martínez-Blanco, J., Gabarrell, X., Artola, A., Sánchez, A., Rieradevall, J., & Font, X. (2010). Environmental assessment of home composting. *Resources, Conservation and Recycling*, *54*(11). https://doi.org/10.1016/j.resconrec.2010.01.008

CPHEEO. (2016). *Municipal Solid Waste Management Manual*. http://cpheeo.gov.in/upload/uploadfiles/files/Part1(1).pdf

DeLaune, P. B., Moore, P. A., Daniel, T. C., & Lemunyon, J. L. (2004). Effect of Chemical and Microbial Amendments on Ammonia Volatilization from Composting Poultry Litter. *Journal of Environmental Quality*, *33*(2). https://doi.org/10.2134/jeq2004.7280

DTU. (2018). *Environment Impact Assessment Report*. http://environmentclearance.nic.in/writereaddata/EIA/0708201915UVXU1M00EIAss.pdf

Ferronato, N., Rada, E. C., Gorritty Portillo, M. A., Cioca, L. I., Ragazzi, M., & Torretta, V. (2019). Introduction of the circular economy within developing regions: A comparative analysis of advantages and opportunities for waste valorization. *Journal of Environmental Management*, *230*. https://doi.org/10.1016/j.jenvman.2018.09.095

Ferronato, N., & Torretta, V. (2019). Waste mismanagement in developing countries: A review of global issues. In *International Journal of Environmental Research and Public Health* (Vol. 16, Issue 6). https://doi.org/10.3390/ijerph16061060

Finstein, M. S., & Morris, M. L. (1975). Microbiology of Municipal Solid Waste Composting. *Advances in Applied Microbiology*, *19*(C). https://doi.org/10.1016/S0065-2164(08)70427-1

Forsyth, W. G. C., & Webley, D. M. (1948). THE MICROBIOLOGY OF COMPOSTING II. A Study of the Aerobic Themophilic Bacterial Flora Developing in Grass Composts. *Proceedings of the Society for Applied Bacteriology*, *11*(1). https://doi.org/10.1111/j.1365-2672.1948.tb03857.x

Franklin-Johnson, E., Figge, F., & Canning, L. (2016). Resource duration as a managerial indicator for Circular Economy performance. *Journal of Cleaner Production*, *133*. https://doi.org/10.1016/j.jclepro.2016.05.023

Geng, Y., Tsuyoshi, F., & Chen, X. (2010). Evaluation of innovative municipal solid waste management through urban symbiosis: A case study of Kawasaki. *Journal of Cleaner Production*, *18*(10–11). https://doi.org/10.1016/j.jclepro.2010.03.003

Guo, R., Li, G., Jiang, T., Schuchardt, F., Chen, T., Zhao, Y., & Shen, Y. (2012). Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost. *Bioresource Technology*, *112*. https://doi.org/10.1016/j.biortech.2012.02.099

Hachicha, S., Sellami, F., Cegarra, J., Hachicha, R., Drira, N., Medhioub, K., & Ammar, E. (2009). Biological activity during co-composting of sludge issued from the OMW evaporation ponds with poultry manure-Physico-chemical characterization of the processed organic matter. *Journal of Hazardous Materials*, *162*(1). https://doi.org/10.1016/j.jhazmat.2008.05.053

Harir, A. I., Kasim, R., Ishiyaku, B., Professor, A., & Fellows, P. (2015). Exploring the Resource Recovery Potentials of Municipal Solid Waste: A review of solid wastes composting in Developing Countries. *International Journal of Scientific and Research Publications*, *5*(4).

Hartz, T. K., & Giannini, C. (1998). Duration of composting of yard wastes affects both physical and chemical characteristics of compost and plant growth. *HortScience*, *33*(7). https://doi.org/10.21273/hortsci.33.7.1192

Hoyle, D. A., & Mattingly, G. E. G. (1954). Studies on composts prepared from waste materials. I.—preparation, nitrogen losses and changes in 'soluble nitrogen.' *Journal of the Science of Food and Agriculture*, *5*(1). https://doi.org/10.1002/jsfa.2740050109

Hu, M., Fan, B., Wang, H., Qu, B., & Zhu, S. (2016). Constructing the ecological sanitation: A review on technology and methods. In *Journal of Cleaner Production* (Vol. 125). https://doi.org/10.1016/j.jclepro.2016.03.012

Huerta-Pujol, O., Soliva, M., Giró, F., & López, M. (2010). Heavy metal content in rubbish bags used for separate collection of biowaste. *Waste Management*, *30*(8–9). https://doi.org/10.1016/j.wasman.2010.03.023

Insam, H., & de Bertoldi, M. (2007). Chapter 3 Microbiology of the composting process. *Waste Management Series*, *8*. https://doi.org/10.1016/S1478-7482(07)80006-6

Ismail, B. P. (2017). *Ash Content Determination*. https://doi.org/10.1007/978-3-319-44127-6_11

Jain, N., Bhatia, A., & Pathak, H. (2014). Emission of air pollutants from crop residue burning in India. *Aerosol and Air Quality Research*, *14*(1). https://doi.org/10.4209/aaqr.2013.01.0031

Janczak, D., Malińska, K., Czekała, W., Cáceres, R., Lewicki, A., & Dach, J. (2017). Biochar to reduce ammonia emissions in gaseous and liquid phase during composting of poultry manure with wheat straw. *Waste Management*, *66*. https://doi.org/10.1016/j.wasman.2017.04.033

Jurado, M. M., Suárez-Estrella, F., López, M. J., Vargas-García, M. C., López-González, J. A., & Moreno, J. (2015). Enhanced turnover of organic matter fractions by microbial stimulation during lignocellulosic waste composting. *Bioresource Technology*, *186*. https://doi.org/10.1016/j.biortech.2015.03.059

Khan, N., Clark, I., Sánchez-Monedero, M. A., Shea, S., Meier, S., & Bolan, N. (2014). Maturity indices in co-composting of chicken manure and sawdust with biochar. *Bioresource Technology*, *168*. https://doi.org/10.1016/j.biortech.2014.02.123

Khater El Sayed. (2016). *BIOLOGICAL ENGINEERING EFFECT OF AMBIENT TEMPERATURE AND AIR FLOW RATE ON THE TEMPERATURE INSIDE THE COMPOST PILE*.

Lazcano, C., Gómez-Brandón, M., & Domínguez, J. (2008). Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. *Chemosphere*, *72*(7). https://doi.org/10.1016/j.chemosphere.2008.04.016

López, M., Soliva, M., Martínez-Farré, F. X., Bonmatí, A., & Huerta-Pujol, O. (2010). An assessment of the characteristics of yard trimmings and recirculated yard trimmings used in biowaste composting. *Bioresource Technology*, *101*(4). https://doi.org/10.1016/j.biortech.2009.09.031

Mahimairaja, S., Bolan, N. S., Hedley, M. J., & Macgregor, A. N. (1990). Evaluation of methods of measurement of nitrogen in poultry and animal manures. *Fertilizer Research*, *24*(3). https://doi.org/10.1007/BF01073582

Mandal, S., Thangarajan, R., Bolan, N. S., Sarkar, B., Khan, N., Ok, Y. S., & Naidu, R. (2016). Biochar-induced concomitant decrease in ammonia volatilization and increase in nitrogen use efficiency by wheat. *Chemosphere*, *142*. https://doi.org/10.1016/j.chemosphere.2015.04.086

Martens, W., & Böhm, R. (2009). Overview of the ability of different treatment methods for liquid and solid manure to inactivate pathogens. *Bioresource Technology*, *100*(22). https://doi.org/10.1016/j.biortech.2009.01.014

Mieldažys, R., Jotautienė, E., Jasinskas, A., Pekarskas, J., & Zinkevičienė, R. (2019). Investigation of physical-mechanical properties and impact on soil of granulated manure compost fertilizers. *Journal of Environmental Engineering and Landscape Management*, *27*(3). https://doi.org/10.3846/jeelm.2019.10794

Mukunth, V. (2020). *Organic city compost 2*. https://public.flourish.studio/visualisation/4182845/?utm_source=showcase&utm_campaign=visualisation/4182845

Nakasaki, K., & Hirai, H. (2017). Temperature control strategy to enhance the activity of yeast inoculated into compost raw material for accelerated composting. *Waste Management*, *65*. https://doi.org/10.1016/j.wasman.2017.04.019

Nakasaki, K., Yaguchi, H., Sasaki, Y., & Kubota, H. (1993). Effects of ph control on composting of garbage. *Waste Management & Research*, *11*(2). https://doi.org/10.1177/0734242X9301100204

Neugebauer, M., & Sołowiej, P. (2017). The use of green waste to overcome the difficulty in small-scale composting of organic household waste. *Journal of Cleaner Production*, *156*. https://doi.org/10.1016/j.jclepro.2017.04.095

Onwosi, C. O., Igbokwe, V. C., Odimba, J. N., Eke, I. E., Nwankwoala, M. O., Iroh, I. N., & Ezeogu, L. I. (2017). Composting technology in waste stabilization: On the methods, challenges and future prospects. In *Journal of Environmental Management* (Vol. 190). https://doi.org/10.1016/j.jenvman.2016.12.051

Oviedo-Ocaña, E. R., Dominguez, I., Komilis, D., & Sánchez, A. (2019). Co-composting of Green Waste Mixed with Unprocessed and Processed Food Waste: Influence on the Composting Process and Product Quality. *Waste and Biomass Valorization*, *10*(1). https://doi.org/10.1007/s12649-017-0047-2

Paes, L. A. B., Bezerra, B. S., Deus, R. M., Jugend, D., & Battistelle, R. A. G. (2019). Organic solid waste management in a circular economy perspective – A systematic review and SWOT analysis. *Journal of Cleaner Production*, *239*. https://doi.org/10.1016/j.jclepro.2019.118086

Pagans, E., Barrena, R., Font, X., & Sánchez, A. (2006). Ammonia emissions from the composting of different organic wastes. Dependency on process temperature. *Chemosphere*, *62*(9). https://doi.org/10.1016/j.chemosphere.2005.06.044

Pagans, E., Font, X., & Sánchez, A. (2006). Emission of volatile organic compounds from composting of different solid wastes: Abatement by biofiltration. *Journal of Hazardous Materials*, *131*(1–3). https://doi.org/10.1016/j.jhazmat.2005.09.017

Petric, I., Helić, A., & Avdić, E. A. (2012). Evolution of process parameters and determination of kinetics for co-composting of organic fraction of municipal solid waste with poultry manure. *Bioresource Technology*, *117*. https://doi.org/10.1016/j.biortech.2012.04.046

Rashid, M. I., & Shahzad, K. (2021). Food waste recycling for compost production and its economic and environmental assessment as circular economy indicators of solid waste management. *Journal of Cleaner Production*, *317*. https://doi.org/10.1016/j.jclepro.2021.128467

Ravindra, K., Sidhu, M. K., Mor, S., John, S., & Pyne, S. (2016). Air Pollution in India: Bridging the Gap between Science and Policy. *Journal of Hazardous, Toxic, and Radioactive Waste*, *20*(4). https://doi.org/10.1061/(asce)hz.2153-5515.0000303

Ravindra, K., Singh, T., & Mor, S. (2019). Emissions of air pollutants from primary crop residue burning in India and their mitigation strategies for cleaner emissions. *Journal of Cleaner Production*, *208*. https://doi.org/10.1016/j.jclepro.2018.10.031

Ravindra, K., Singh, T., & Mor, S. (2022). COVID-19 pandemic and sudden rise in crop residue burning in India: issues and prospects for sustainable crop residue management. *Environmental Science and Pollution Research*, *29*(2). https://doi.org/10.1007/s11356-021-17550-y

Roy, D., Azaïs, A., Benkaraache, S., Drogui, P., & Tyagi, R. D. (2018). Composting leachate: characterization, treatment, and future perspectives. In *Reviews in Environmental Science and Biotechnology* (Vol. 17, Issue 2). https://doi.org/10.1007/s11157-018-9462-5

Ruggieri, L., Gea, T., Artola, A., & Sánchez, A. (2009). Air filled porosity measurements by air pycnometry in the composting process: A review and a correlation analysis. In *Bioresource Technology* (Vol. 100, Issue 10). https://doi.org/10.1016/j.biortech.2008.12.049

Sudharsan Varma, V., & Kalamdhad, A. S. (2015). Evolution of chemical and biological characterization during thermophilic composting of vegetable waste using rotary drum composter. *International Journal of Environmental Science and Technology*, *12*(6). https://doi.org/10.1007/s13762-014-0582-3

The World Bank. (2022). *Solid Waste Management*. https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management

Tiseo, I. (2020). *Solid waste treatment plants India 2019, by type*. https://www.statista.com/statistics/1061462/india-solid-waste-treatment-plants-by-type/

WHO. (2021). *Ambient (outdoor) air pollution*. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

WHO. (2022). *Drinking-water*. https://www.who.int/news-room/fact-sheets/detail/drinking-water

Wilson, D. C., Araba, A. O., Chinwah, K., & Cheeseman, C. R. (2009). Building recycling rates through the informal sector. *Waste Management*, *29*(2). https://doi.org/10.1016/j.wasman.2008.06.016

Yang, F., Li, G., Shi, H., & Wang, Y. (2015). Effects of phosphogypsum and superphosphate on compost maturity and gaseous emissions during kitchen waste composting. *Waste Management*, *36*. https://doi.org/10.1016/j.wasman.2014.11.012

Zang, B., Li, S., Michel, F., Li, G., Luo, Y., Zhang, D., & Li, Y. (2016). Effects of mix ratio, moisture content and aeration rate on sulfur odor emissions during pig manure composting. *Waste Management*, *56*. https://doi.org/10.1016/j.wasman.2016.06.026

Zhang, H., Li, G., Gu, J., Wang, G., Li, Y., & Zhang, D. (2016). Influence of aeration on volatile sulfur compounds (VSCs) and NH3 emissions during aerobic composting of kitchen waste. *Waste Management*, *58*. https://doi.org/10.1016/j.wasman.2016.08.022

Zhang, L., & Sun, X. (2016). Improving green waste composting by addition of sugarcane bagasse and exhausted grape marc. *Bioresource Technology*, *218*. https://doi.org/10.1016/j.biortech.2016.06.097