Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Effect of Bulking Agent on Composting and Greenhouse Gas (GHG) Emissions of Organic Fraction of Municipal Solid Waste

Hajra Maalik*
Works as Environment Specialist at Resilience Gateway Pvt. Limited, Degree of Master of Science in Environmental Science from National university of science and Technology NUST Islamabad. Corrosponding Author Email: hajramaalik@gmail.com
Ayesha Abdul Malik
Mphil Scholar , National University of Modern Languages Islamabad , Department of Pakistan Studies

ABSTRACT

Solid waste generation is increasing day by day globally. Similarly, in Pakistan more than 50% of the municipal solid waste is biodegradable and contributes to greenhouse gas (GHG) emissions if not managed properly. To address this issue there's a need to use a waste management technique that is economically feasible, environmentally friendly, and practically possible. Composting of organic fraction of municipal solid waste is one of the promising techniques for converting waste into a resource. This study was aimed to convert waste (organic fraction of municipal solid waste) into a resource (compost) using three different bulking agents (wood shavings, dry leaves, and corn stalks) in three different reactors. The composting mixture was monitored for its characteristics like temperature, moisture content, TS, VS, TOC, TKN, C/N ratio, TP, and pH. Secondly, the GHG emission potential of compost was determined at different stages of compost formation. The final compost using three different bulking agents had C/N ratio of 20.6, 15 and 12.4 for wood shavings, dry leaves, and corn stalks respectively that is considered an ideal value for mature and stable compost. The results of GHG emission potential showed that raw waste had maximum GHG potential of 3114, 2926 and 2833 g CO_2eq/kg compost for wood shavings, dry leaves and corn stalks respectively as compared to final compost having GHG emission potential of 934, 832 and 736 g CO_2eq/kg compost for wood shavings, dry leaves and corn stalks respectively. Moreover, the net GHG emissions were found to be minimum and almost similar for all the three bulking agents in the final compost. Together, the results showed that composting of waste with bulking agents can produce a stable compost and can significantly reduce the GHG emissions.

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Introduction

This article provides an overview of the critical issue of the management of solid waste, with a specific focus on the organic portion of municipal solid waste (MSW) in Pakistan. As the global population is growing at a continuous rate and, improvement in the standards of living, the solid waste generation is also increasing at a rate that is quite alarming. A significant portion of household waste is biodegradable in many Asian countries, including Pakistan, posing serious challenges for the management of waste.

Solid Waste

Solid waste generation is increasing day by day globally, not only because the population is growing, but also due to improvement in our living standards. It is estimated that in Asian countries about 40 to 60 percent of the waste at household level is of biodegradable nature. Improper management and disposal of such a huge quantity of organic solid waste poses serious impacts on air, land, water and human health. It is estimated that landfills and dumps of solid waste are the contributor of greenhouse gas that is 2 %, consisting mainly of methane (Zeshan & Visvanathan, 2014). Asian countries are generating the municipal solid waste at the rate of 1 million tons per day and it is believed that this rate will increase to about 1.8 million tons per day by the year 2025 which is quite alarming. More than 50 % of the municipal solid waste is of organic nature in Asian countries. Municipal solid waste includes paper waste, yard waste, wood waste, food waste, bottle, textiles etc (Sohoo et al., 2021). Currently, municipal solid waste management practices that are environmentally sound are absent in Pakistan. About 60 to around 70% of municipal solid waste is collected but the collection rate is greater in bigger cities as compared to smaller cities. And after collection of this waste, about 50 % of the municipal solid waste is disposed of in the form of open dumping and 40 % of the municipal solid waste is sent to landfill sites that are not even specified in case of Pakistan (Khatri et al., 2021). The rate at which developing countries are generating the solid waste is 0.5 kg/ person/day and the average solid waste that is being generated per day in Pakistan is 71000 tons. Resource circulation of waste is mostly carried out through the process of recycling that is 8% and through composting that is just 2%. The figure given below shows the composition of municipal solid waste in Pakistan. And it can be seen from the figure that food waste and yard waste are the two major components of municipal solid

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

waste in Pakistan. Out of the total composition of MSW, 30 % is food waste, 14 % is yard waste, 7% is cardboard and 6 % is paper waste, which is given below in **Figure 1.1.** Since organic fraction forms the major component of municipal solid waste in Pakistan, effective treatment of this fraction is very important for efficient management of waste (Devadoss et al., 2021).

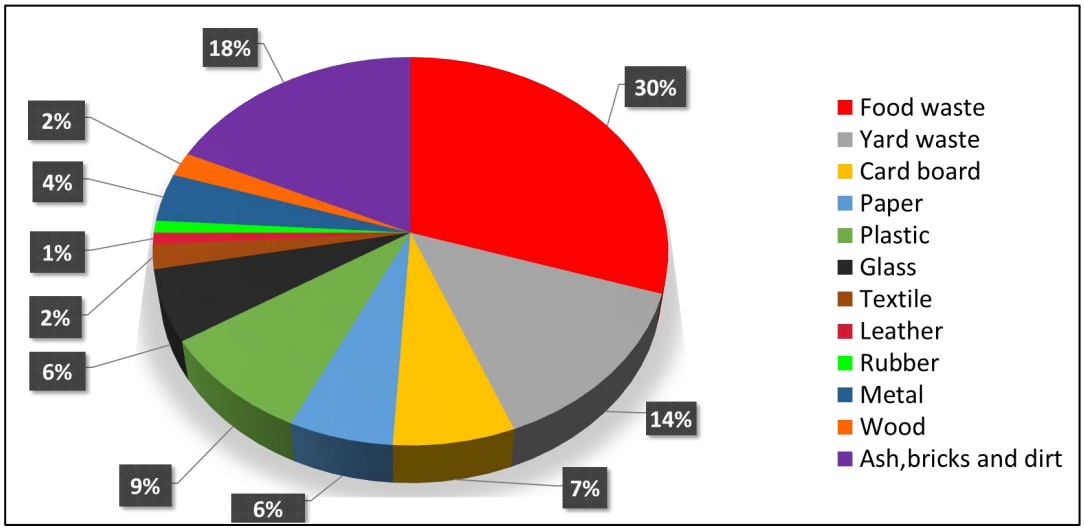


Figure 1. 1 Composition of MSW in Pakistan

Various technologies are available for management of organic waste and its reuse such as incineration and anaerobic digestion for the production of thermal energy, electricity and fuel. But these techniques are quite expensive, complicated and require technical expertise for their operations (Khalid et al., 2022). Traditionally, in both developed and developing nations, food waste is often disposed of inappropriately, either through open dumping, incineration, or as animal feed. As far incineration is concerned, the fly ash from incinerators has high levels of toxic chemicals, posing serious environmental and public health risks. Moreover, in 2013, the Food and Agriculture Organization reported that yearly greenhouse gas emissions resulting from food waste in landfills were nearly equivalent to the total emissions of Cuba i.e. approximately 3.3 billion tons of CO_2 annually. Furthermore, food waste was found to contribute significantly to global water loss, estimated at roughly 250 cubic kilometers each year. Consequently, food waste management has emerged as a significant environmental challenge, given its rich organic content and high biodegradability (Verma et al., 2023).

So, we need technology for the management of organic waste that is relatively simpler,

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

cheap and has insignificant environmental impacts. Considering these factors, composting emerges as a promising technique that aligns with these criteria, providing an eco-friendly solution for managing organic waste and the end product can be used as a soil conditioner. Composting is a widely adopted method for the disposal of food waste. It involves the metabolic activities of microorganisms, harnessing their catabolic and anabolic processes to break down complex macromolecules like starch, fats, and proteins in the initial stage. Further, these components hydrolyze to form glucose, fatty acids, and peptides. Over time, these smaller compounds undergo further degradation and condensation, ultimately forming stable humic substances (Zhu et al., 2023). Amongst, aerobic composting is recognized as a more reliable method since it not only breaks down waste effectively but is also a good source for production of mature and stable compost, which widely employed as fertilizer or soil conditioner.

Various physicochemical parameters including pH, organic matter (OM), total nitrogen (TN), and total phosphorus (TP) affect the composting process by regulating microbial activities. These microbial activities, in turn, exert direct and indirect effects on the bioavailability of heavy metals (Guo et al., 2022). The moisture content within the composting mixture also holds significant importance since it serves as a medium that facilitates the movement of essential dissolved nutrients required to support the metabolic and physiological functions of microorganisms. Similarly, the carbon-to-nitrogen (C/N) ratio is also a crucial factor influencing both the composting process and the characteristics of the final product (Kumar et al., 2010).

Furthermore, the aeration rate also plays a vital role in the composting process, it is generally recommended to maintain 30% free air space when preparing the compost mixture. This percentage may fluctuate based on the particular substrate and composting system employed (Adhikari et al., 2008). Insufficient aeration, as well as excessive aeration, can lead to undesirable outcomes such as increased nitrogen loss and immature compost as an end product (Wang et al., 2021). (Zeng et al., 2018) reported that intermittent aeration can significantly reduce greenhouse gas emissions by 12.36% to 53.20% when compared to continuous aeration.

Studies indicate that the application of compost yields favorable outcomes and enhances soil fertility. Although composting is the most widely used technique globally for treatment of organic solid waste, but there are some issues in the process of composting

Online ISSN 3007-3197
Print ISSN 3007-3189

such as low porosity of composting piles, longer time period required for degradation of waste, excessive moisture present in the food waste, generation of GHG emissions, which restricts the evolution of the composting process. So, we need to optimize the composting process in a practical and economic way. These issues are addressed through the introduction of bulking agents for optimizing the composting process (Zahra et al., 2023).

The composting process can be enhanced by incorporating bulking agents. These bulking agents help in improving aerobic conditions, managing gaseous emissions, accelerating biodegradation, and promoting product maturation by adjusting substrate physicochemical parameters such as C/N ratio and moisture content (Xu et al., 2021). The composition of bulking agents, including their C/N ratio and moisture content, varies depending on the specific materials used. For instance, wood chips typically have a high C/N ratio, and their moisture content depends on how dry they are; the high carbon content in wood chips is primarily in the form of lignin, which is resistant to biological degradation. On the other hand, materials like wheat straw and hay have a lower C/N ratio and their carbon content is more easily degradable (Adhikari et al., 2008). Moreover, adding vine shoot pruning as a bulking agent during the composting of food waste can accelerate the process, mitigate nitrogen losses, and enhance the overall stability of compost (Li et al., 2022). There are several bulking agents that can be used for the optimization of the composting process. The bulking agents used in this study were wood shavings, dry leaves, and corn stalks. The selection of these bulking agents was based on their excellent value both as a bulking agent and a carbon source.

Similarly, characteristics of food waste may also vary depending upon the component of waste such as Lettuce, onions, tomatoes, and cabbage contain more nitrogen (N) in their fresh weight (FW) when compared with potato tops, whole carrots, peppers, and bread. Before starting the composting process, it is crucial to thoroughly understand the characteristics of the food waste and the selected bulking agent. This knowledge allows for the formulation of a balanced recipe that considers moisture content to ensure proper aeration, pH levels for creating an optimal microbial environment, and the right balance of carbon and nitrogen to support microbial growth and development (Adhikari et al., 2008).

Materials And Methods

The purpose of this chapter, "Materials and Methods," is to give a thorough

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

description of the materials and methodologies utilized in this investigation into the impact of bulking agents on the organic portion of municipal solid waste's composting and greenhouse gas emissions. Understanding the composition and the type of waste is a crucial step in the composting process since it has a significant impact on the effectiveness and quality of the compost that is produced.

Study Area Description

Before starting the composting process, it is very important to thoroughly understand the type and composition of waste. The compost feedstock was comprised of vegetables, fruit waste and inoculum which was ready made compost. Specifically, food waste including banana peels, apple peels, and potato peels was taken from Concordia -1 NUST, Islamabad. While rotten vegetables including spinach and pumpkin were acquired from Sabzi mandi, located in Itwar Bazar, Islamabad. The location map from where the samples were taken for this research is shown below in Figure 3.1.

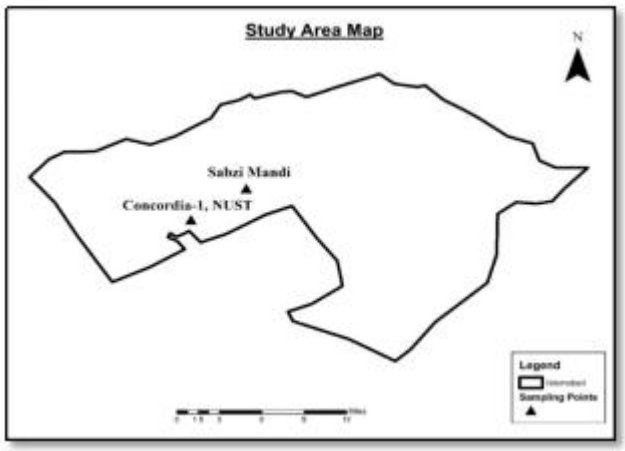


Figure 3. 1 Study Area Map

The composition of food waste, inoculum, and bulking agents in grams is shown below in **Table 3.1.** All the peels and vegetables were used in the same ratio which is given below in **Table 3.2.**

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Table 3. 1 Composition Of Waste For Composting Process

Waste Composition (kg)	
Total waste	3
Food waste	1.8
Bulking agents (Wood shavings, Dry leaves, Corn stalks)	0.9
Inoculum (ready made compost)	0.3

Table 3. 2 Type of Waste

Type of Waste (g)		
Sr. No.	**Waste type**	**Weight**
1	Potato peels	0.4
2	Apple peels	0.4
3	Banana peels	0.4
4	Spinach	0.4
5	Pumpkin	0.4
	Total	2.0

These conditions were established before starting the composting process given below in **Table 3.3.**

Table 3. 3 Composting conditions

Waste Composition (kg)	
Particle size of waste	1 to 2 cm
Aeration rate	0.1 L/kg/hr
Moisture content	40-60%
Number of days for composting	35 days
Thorough mixing of waste	Every 3rd day
Sampling of waste	Once a week

Design And Working Of Reactors For Composting Process

The composting experiment was conducted in three stainless steel reactors with a volumetric capacity of 5 liters each. The reactors exhibited dimensions of 25 cm in height

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

and 16 cm in diameter, providing an enclosed conducive to the composting process. The reactors were equipped with two ports i.e., one for leachate collection and the other for aeration purposes. The reactors were designed to have removable lids, allowing them to be opened during sample collection and facilitating manual mixing of the waste for homogeneity. Approximately 3 kg of thoroughly blended feedstock was introduced into each reactor. This composition included 0.9 kg of a bulking agent, 0.3 kg of inoculum and the remaining portion consisted of food waste that is 1.8 kg. In each reactor, a distinct bulking agent was employed as part of the composition. For the reactors, one was filled with corn stalks, another with dry leaves, and the third with wood shavings. These individual selections of bulking agents contributed to the diversity of the experimental setup. Additionally, temperature sensors were affixed to the reactor to ensure a controlled temperature environment throughout the experiment. The reactors were sealed using screws to prevent contact with air. To conduct the experiment systematically, a total of three reactors were employed having similar dimensions and specifications. All three reactors were connected with an aerator to facilitate aerobic composting. Aeration was provided from the bottom to all three reactors to maintain the aeration rate of 0.107 L/kg/hr throughout the entire process.

The whole composting process was carried out over the time frame of 35 days. Samples were methodically gathered on a weekly basis after thorough homogenization, and leachate extraction was also performed each week. The schematic representation of the compositing setup is shown in **Figure 3.2.**

Wood shavings, corn stalks, and dry leaves which are commonly used bulking agents in the process of composting were used for comparing the effect of these bulking agents on the overall stability and maturity of the compost. Wood shavings were collected from construction site H-13, Islamabad. Dry leaves were collected from a nearby park while corn stalks were taken from a local agriculture residue shop, located at 1-10, Islamabad. While preparing each pile for the three reactors, different raw organic materials such as vegetables (spinach, potato peels, and pumpkin) and fruit peels (apple and banana peels) were mixed thoroughly with a fixed ratio of bulking agents (Wood shavings, Dry leaves, and Cornstalk) These bulking agents were added to waste to improve aeration, achieve required C/N ratio for effective decomposition, enhance moisture management, and create spaces within the pile for better microbial activity. The

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

characteristics of feedstock material are presented in **Table 3.4.** The total nitrogen concentration, C/N ratio, moisture content, volatile solids, and carbon percentage of the different organic components are compared in the table. Notably, wood shavings have the highest volatile solids content (98%), pumpkin has the highest moisture content (93%), dry leaves have the highest total solids (92%), and apple peels have the highest C/N ratio (112.50). Additionally, wood shavings have the highest carbon percentage (54.44%).

The composition of the waste mixture, inoculum and bulking agents in each of the three reactors is presented in **Table 3.5.**

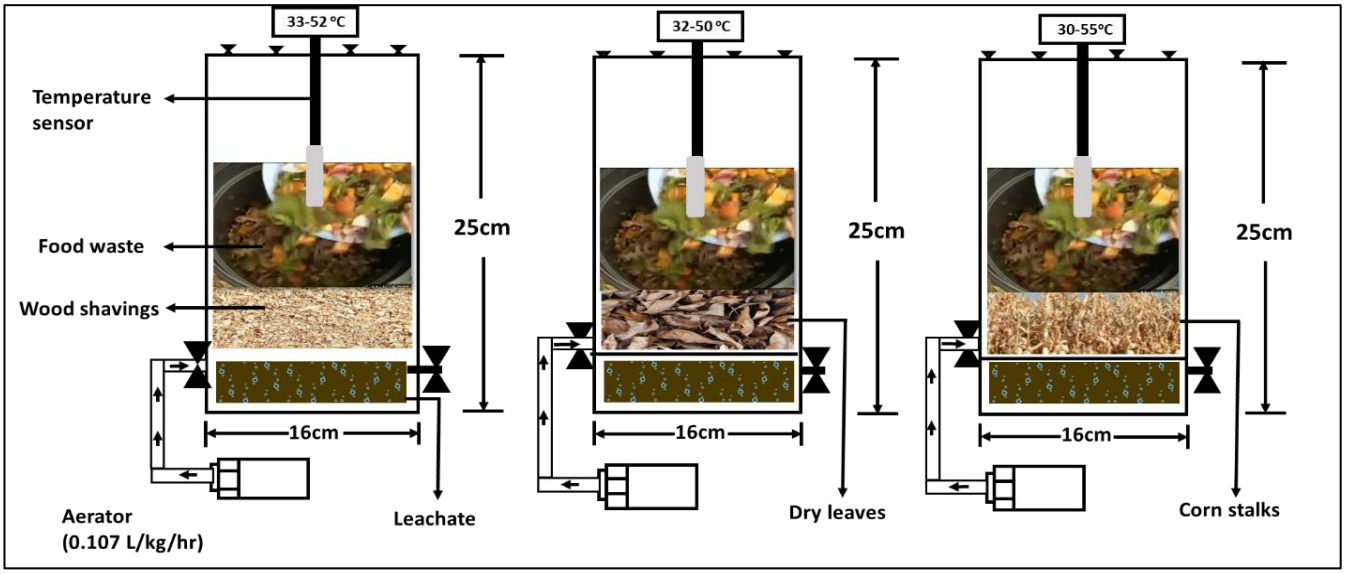


Figure 3. 2 Schematic Representation Of Composting Setup

Table 3. 4 Physicochemical characteristics of feedstock

Parameters	Potato peels	Apple peels	Banana peels	Spinach	Pumpkin	Dry leaves	Wood shavings	Corn stalk
Total nitrogen (%)	1.22	0.40	1.40	3.50	4.30	1.20	0.30	0.70
C/N ratio	36.88	112.50	32	12.85	10.46	37.50	150	64
Total solids (%)	18.70	21.30	12.20	17	7	92	91	84
Moisture content (%)	81.30	78.70	87.80	83	93	8	9	16

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

Volatile solids (%)	81.00	95	83.10	82	85	81	98	91
Carbon (%)	45.00	52.78	46.17	45.56	47.22	45.00	54.44	50.56

Table 3. 5 Reactors Composition

Reactors	Reactor composition
Reactor-1	60wt% mixed fruit and vegetables+30wt% Wood shavings as a bulking agent+ 10% wt inoculum
Reactor-2	60 wt% mixed fruit and vegetables+30wt% Dry leaves as a bulking agent + 10% wt inoculum
Reactor-3	60 wt% mixed fruit and vegetables+30 wt% Cornstalks as a bulking agent + 10% wt inoculum

Physicochemical Analysis

Method to Determine pH

A digital pH meter was used to measure the pH of the compost. For that 1 gram of sample from all three reactors was taken and mixed with 10 ml of distilled water and mixed thoroughly for 30 minutes (Xiao et al., 2009) pH and electrical conductivity analyses were conducted utilizing a multimeter (in Lab pH/COD 720, Germany) to ensure precise readings.

Method to Determine Temperature

The temperature was measured using a thermocouple at the core of compost piles of all three reactors and was recorded using a digital meter attached at the top of all three reactors.

Method To Measure Total Nitrogen, Total Solids, Moisture Content, And Volatile Solids

Parameters such as total Kjeldahl nitrogen, total solids and volatile solids were measured using the standardized procedure outlined in APHA (2017). Total solids were measured using an established method that involves drying the sample in an oven at 105° C for 24 hours. In this way, both total solids and moisture content were calculated. Volatile solids were determined on the basis of percentage of residue after heating in a muffle furnace for 30 minutes. Total Kjeldahl nitrogen was measured using the regular Kjeldahl process.

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Method to Measure Total Phosphorus (TP)

For the measurement of total phosphorus, the perchloric acid digestion method as detailed by Sommers et al. (1972) was used. For analysis of compost, 1 g of thoroughly mixed compost sample was placed in the digestion tube- Folin-Wu digestion tubes, and then 3 ml of the 70% of $HClO_4$ was added. After that, digestion tubes were put in the aluminum digestion block and digested for 75 min at a temperature of 203°C. When digestion was complete, the digest was allowed to cool and then diluted with 50 ml of distilled water. The tubes were then stoppered and inverted several times for a thorough mixing of the content present in the tubes. Then, the residue was removed from the extract by filtration for immediate P analysis. After that, 3 ml of extractant was pipette into test tubes, and then 3 ml of mixed reagent was added by a pipette. The mixed reagent comprises:

1. Distilled water-200 ml
2. 4M Sulphuric acid- 50 ml
3. Ammonium molybdate solution- 15ml
4. Ascorbic acid solution- 30 ml
5. Potassium antimony tartrate solution- 5ml

The samples were then homogenized using a vortex meter for 30 min for the development of blue color. Then read the absorbance of samples in a spectrophotometer and set a wavelength of 400nm. Then the below-mentioned equation was used for measuring the total phosphorus present in the compost.

Calculation:

$$\text{mg P } kg^{-1} = (a - b) \times V \times 1L \times 1000\ g \times DF \times mcf\ W/1000\ mL \times 1kg$$

$$= (a - b) \times V \times DF \times mcf\ /W$$

Where:

a = concentration of P in sample extract, mg L^{-1}

b = concentration of P in blank, mg L^{-1}

V = volume of extractant, mL

W = weight of soil sample, g

DF = dilution factor = total volume of diluted sample solution/aliquot of extract, mL mL^{-1}

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

mcf = moisture correction factor

Estimation of GHG Emissions from Compost

This part of the study includes estimating the GHG emission potential at various stages of compost formation. The GHG (Methane and Nitrous oxide) emission potential before, during, and after the compost formation was calculated using the method given in section- below. The detailed methodology for estimating the GHG emissions potential is given in the following subsections.

Calculation Methods

Methane Emission Potential of Compost

Greenhouse gas emissions estimation was assessed using the mass balance method. This method computes methane formation potential based on the carbon content within the material (Zeshan & Visvanathan, 2014).

The detailed stepwise process is given below:

1. The characteristics of the compost, specifically the total solids (TS) and carbon (C) content, were determined through laboratory analysis. These values were then utilized in the calculation of methane formation potential.
2. The methane potential of the material (in grams per kilogram of waste) was transformed into greenhouse gas emissions (in grams of CO_2-equivalents per kilogram of waste) by applying a conversion factor of 25.

The equation used for CH_4 calculation:

CH_4 emission (grams of methane per kilogram of material)

$$= (M \times TS \times MCF \times DOC \times DOCf \times F \times (16/12) - R) \times (1 - OX) \times 1000$$

gram of Carbon dioxide-equivalent/ kilogram = (gram of methane/ kilogram) x25

where M = Total mass of material (kg)

TS = Total solid content (fraction)

MCF = Moisture correction factor. That is 0.4

DOC = Degradable organic carbon (fraction) that is carbon value (VS/1.8 value)

DOCf = Fraction of DOC dissimilated. That is 0.77

F = Fraction of methane gas. That is 0.5

R = Recovered methane. That is 0

OX = Oxidation factor. That is also 0.

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

Calculation of Nitrous Oxide- N_2O Emission from Compost

The land-applied compost, biosolids, or digestate emits nitrous oxide that is equal to 0.01 of the applied nitrogen as specified by the IPCC. In this study, we have used the nitrous oxide emission factor which is 0.013 of applied nitrogen in the compost (Zeshan & Visvanathan, 2014).

The total amount of nitrogen that is provided by 1 kilogram of compost was calculated from the content of nitrogen of each type of compost (compost with wood shavings as a bulking agent, compost with dry leaves as a bulking agent, and compost with corn stalks as bulking agents). The amount of nitrous oxide that is to be emitted from 1 kilogram of the compost was then calculated by using a factor of 0.013 of the nitrogen applied. The amount of nitrous oxide emitted from the compost was then multiplied with the factor of 298, to convert it to the equivalent amount of carbon dioxide- CO_2.

Calculation of Greenhouse Gas (GHG) Avoided by Land Application of Compost

The utilization of compost for land application has the potential to serve as a substitute for synthetic fertilizers, thus contributing to a reduction in the emission of fossil carbon resulting from the energy-intensive production of chemical fertilizers. The total nitrogen (N) and phosphorus (P) content provided by 1 kilogram of compost was determined based on the respective N and P concentrations measured in each compost type. The quantification of greenhouse gas (GHG) emissions avoided or reduced through the land application of compost was subsequently computed using emission factors of 8.9 kilograms of CO_2-equivalents per kilogram of N and 1.8 kilograms of CO_2-equivalents per kilogram of P (Zeshan & Visvanathan, 2014).

Results And Discussion

The study examines the impact of various bulking agents, such as wood shavings, dry leaves, and corn stalks, together with food waste, such as apple, banana, potato, and pumpkin peels, and a ready-made compost inoculum, on the composting process in the Results and Discussion chapter. With an emphasis on reaching the ideal carbon-to-nitrogen ratio, it investigates how different ratios of these components affect the effectiveness of aerobic decomposition in three laboratory-scale reactors.

Characteristics of Waste Mixture at the Start

In this study, three different types of bulking agents along with food waste (Apple peels,

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

banana peels, potato peels, spinach, and pumpkin) and inoculum that was ready-made compost in this case, were used in three different laboratory scale reactors. Then a mixture of bulking agents, food waste, and inoculum was prepared in different proportions to ensure the appropriate conditions at the start of the composting process to achieve an efficient process of aerobic decomposition. The bulking agents that were used in this study were wood shavings, dry leaves, and corn stalks. The aim of using these bulking agents was to adjust the initial carbon-to-nitrogen ratio to be within the recommended value of 25-35 w/w (Al-Nawaiseh et al., 2021a)

Table 4. 1 The physicochemical properties of initial composting piles

Parameters	Compost with wood shavings	Compost with dry leaves	Compost with corn stalks
TKN (%)	1.5	1.84	1.6
C/N	33	25	29
TS (%)	40	40	38
MC (%)	60	60	62
VS (%)	89	83	85
TP (%)	0.037	0.067	0.09
pH	7.8	7.9	8
C (%)	49	46	47
Temp (°C)	33	32	30

The results shown in **Table 4.1**. indicate that the initial C/N ratio for the three piles is within the recommended values for stimulating degradation and immobilization of nitrogen. The initial pH for all three reactors was slightly higher than the recommended value of 6 & 7.5 for the development of microbes (Al-Nawaiseh et al., 2021a). The moisture content for all three reactors was within the recommended value of 50-60% for efficient decomposition of organic substrate.

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Temperature Variation in Compost for Different Bulking Agents

The temperature profiles of the waste mixture were almost similar for all three reactors, which experienced the mesophilic, thermophilic, cooling, and mature stages. All three reactors accomplished their temperature summit within the first 3 - 5 days, given their sharp decomposition of organic substances to create heat. A persistent decline with a few slight fluctuations in temperature happened from that point, with the depletion of promptly biodegradable organic substances. Since microorganisms and organic matter could be redistributed to reactivate metabolic exercises by turning composting piles, the temperature profile showed an increase again on day 14 for all three reactors. From day 24 ahead, the temperature declined to an ambient level without any further increase after turning of waste manually on day 28 (Xu et al., 2021). The temperature variation in compost for different bulking agents has been shown below in **Figure 4.1.**

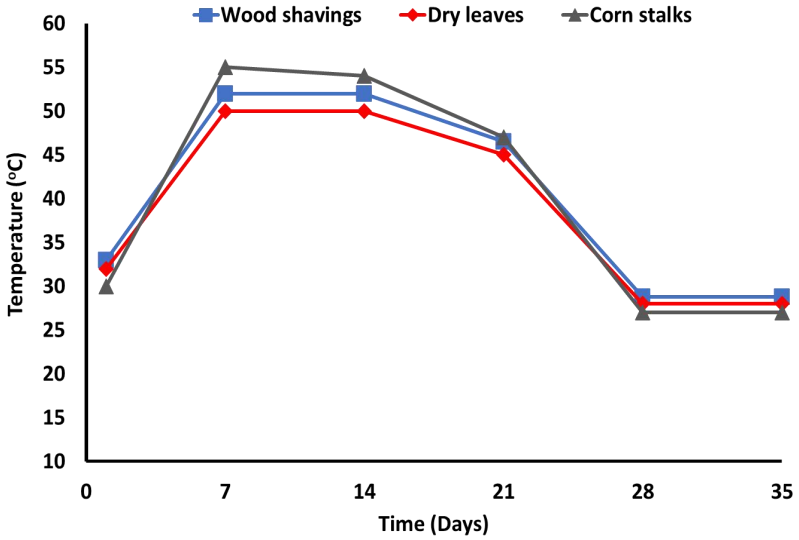


Figure 4. 1 Temperature variations in compost for different bulking agents

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

When cornstalks were used as bulking agents, a slower increase in temperature was observed in the beginning as compared to wood shavings and dry leaves as bulking agents. This might be linked with the softer texture of corn stalks which resultantly reduces the porosity of the matrix for diffusivity of air, slowing down the biodegradation of organic matter as compared to wood shavings and dry leaves as bulking agents. But, since the bulking agent corn stalks contain more bioavailable substances such as hemicellulose and carbohydrates. So, from day 7 onward temperature rapidly increased exceeding the other two treatments.

pH of Compost for Different Bulking Agents

The pH values at the initial stage of the composting process were recorded between 7 and 8 for each of the three reactors. After that, the process of ammonification occurs, where the nitrogen that is organic in nature is transformed into amide and ammoniacal nitrogen, characteristic of its alkaline reaction in the development of NH_3, which likewise causes an increase in the pH in the medium. The final pH of the compost in the reactor with corn stalks as a bulking agent was 9.5, basic, as compared to bulking agents- wood shavings and dry leaves, which had pH values somewhere in the range of 8.5 and 9. This alkaline characteristic in all three reactors might be attributed to least formation of leachate and volatilization of ammonia (Guidoni et al., 2018). The final pH value for all the three reactors was above 8.0 . This higher pH value has an advantage for its in agriculture land with acidic soil. The final pH for all the three treatments is shown in **Figure 4.2**

Volatile Solids In Compost For Different Bulking Agents

Initially volatile solids may be high as organic matter starts to break down. The graphical representation of changes in volatile solids throughout the composting process is shown below in **Figure 4.3.**

As you can see in the graph below, the volatile solids are very high in the beginning of composting process. As the organic matter starts to breakdown, the volatile solids

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

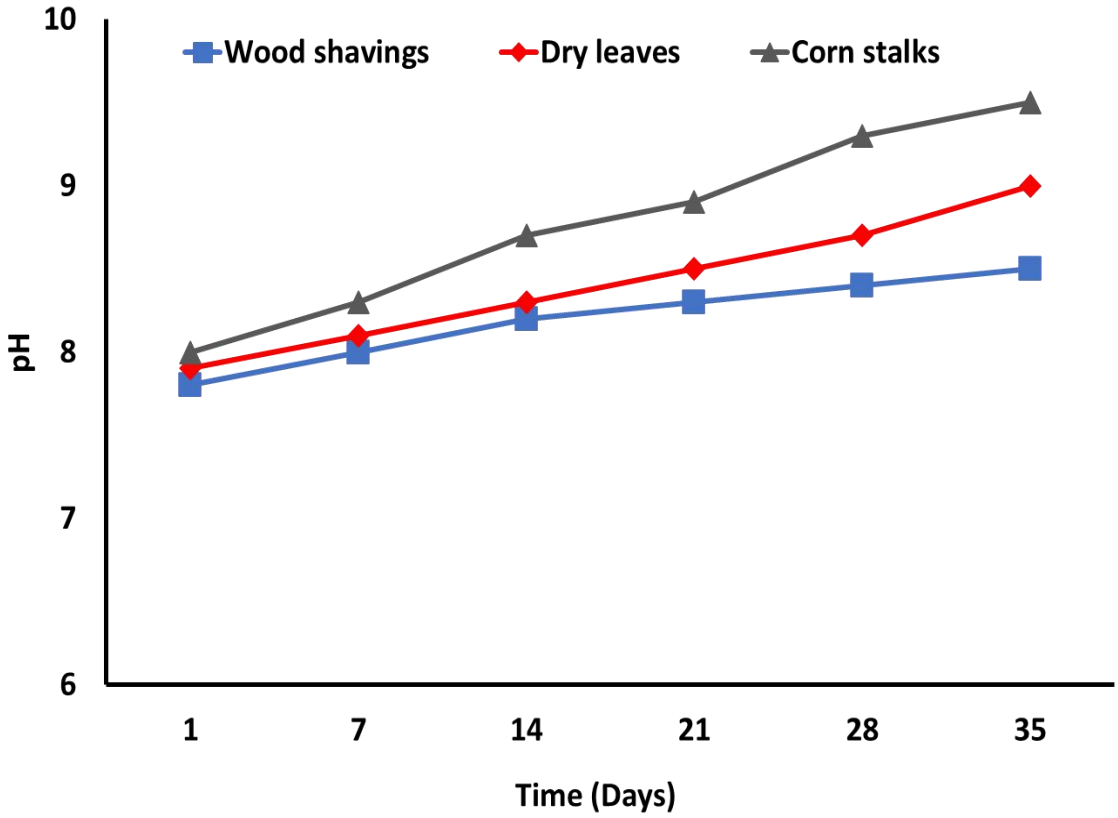


Figure 4. 2 Variation in pH of compost for different bulking agents

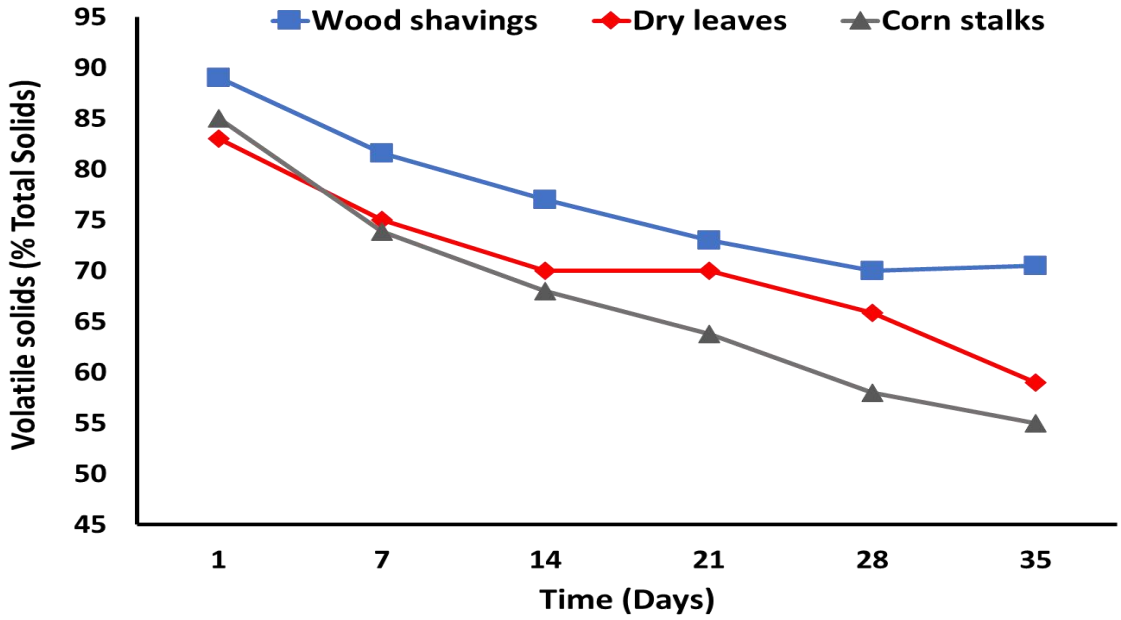


Figure 4. 3 Variation in volatile solids of compost for different bulking agents

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

show a significant reduction at the end of composting process (Al-Nawaiseh et al., 2021). This indicates that organic matter has undergone decomposition and stabilization. The volatile solids in the case of compost with wood shavings show low reduction as compared to the compost with dry leaves and corn stalks. The reason behind this is that wood shavings have high cellulose and lignin content which take greater time for degradation.

Total Organic Carbon In Compost For Different Bulking Agents

The variation in the total organic carbon in all three reactors is presented in the form of graphs. The TOC (Total organic carbon) for all three reactors at the initial stage of the composting process was in the range of 45-49%. Though there were variations in the trend of certain composting mixtures, it was also observed that the TOC content in all composting mixtures decreased during the composting period, with the thermophilic phase experiencing the highest reductions. This general decrease in TOC during the composting period might be attributed to the biodegradation of organic matter which is related to the rise in temperature and total loss of TOC which was in the form of carbon dioxide when the micro organisms utilize this carbon for energy (Ameen & Dohuki, 2022). In comparison to the other two reactors with dry leaves and corn stalks as bulking agents, delay in organic carbon reduction was observed in a reactor with wood shavings as a bulking agent. This delay in TOC reduction in a reactor with wood shavings as BA might be attributed to their initial C/N ratio (33), which is slightly more than the optimum range in comparison to other mixtures. The total carbon variations in compost for different bulking agents are shown below in **Figure 4.4.**

Moisture Content (MC) and Total Solids in Compost for Different Bulking Agents

Moisture content and total solids are interrelated to each other. When the percentage concentration of moisture content is high, then the percentage concentration of total solids is low and when total solids are high then the moisture content is low, and vice versa. At the start of the composting process, the moisture content was high until the 4th week, and total solids were low in all three reactors. After the 4th week, MC was reduced and total solids were increased. The organic materials in the composting pile often absorb water at the start of the process which results in

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

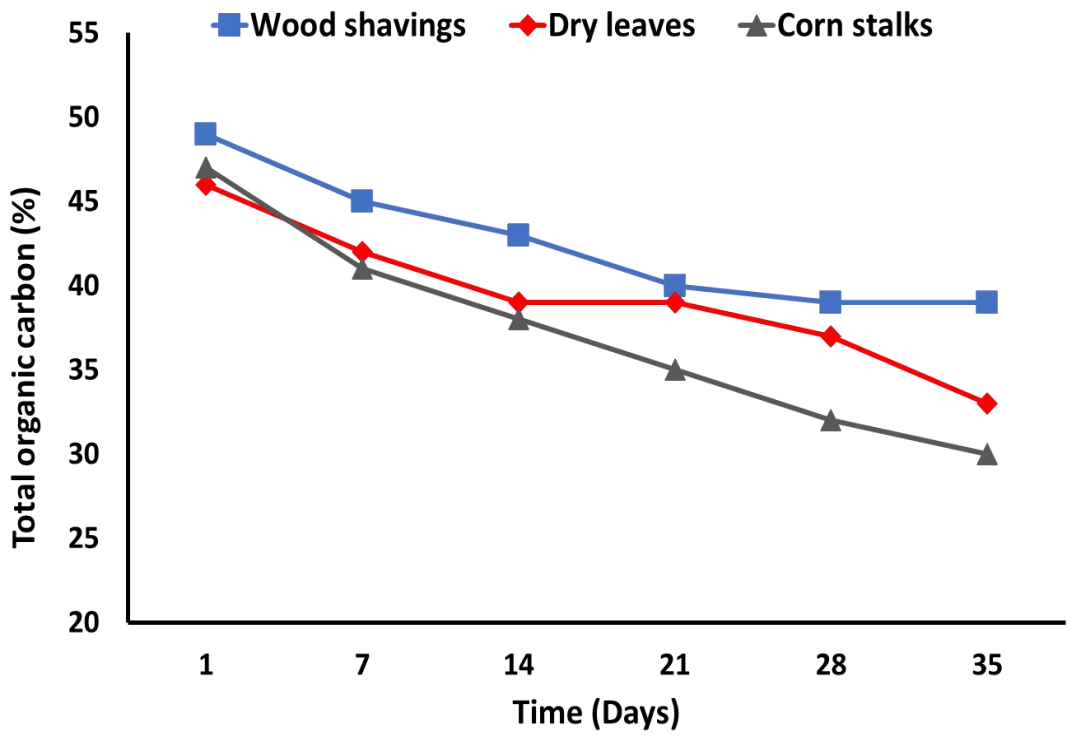


Figure 4. 4 Variation in total carbon in compost for different bulking agents

decreased total solids at the beginning of the composting process. This absorption could lead to an initial increase in moisture content and a reduction in the concentration of total solids temporarily. On the other hand, the microorganisms that are responsible for breakdown consume organic matter as a nutrient and an energy source. This microbial breakdown results in the decomposition of complex organic substances into simpler forms, such as water, carbon dioxide, and microbial biomass. This organic matter conversion into more simpler forms resultantly decreases the total solids.

Moisture content defines the composting fate and the content of nutrients of present in the compost. When moisture content is high it causes the leaching of nutrients and also does not allow the rise of temperature in the compost piles. At the start of the composting process, MC should be in the range of 50–65% from stoping the loss of nutrients from leaching (Zahra et al., 2023). Moisture content at the initial stage of composting was within the recommended range of 50-65 % in all three reactors. But during weeks 3 and 4 moisture content increased in all the reactors. The reason behind this increase was that the experiment was conducted in the months of July and August and there was a lot of humidity in the lab which increased moisture content. But after

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

week 4 the compost from all three reactors was taken out and put in the sunlight to adjust the moisture content and achieve thelevel of optimal range. The MC of the final compost for compost with wood shavings, for compost with dry leaves, and for compost with corn stalks as bulking agents is shown below in **Figure 4.5 and Figure 4.6**

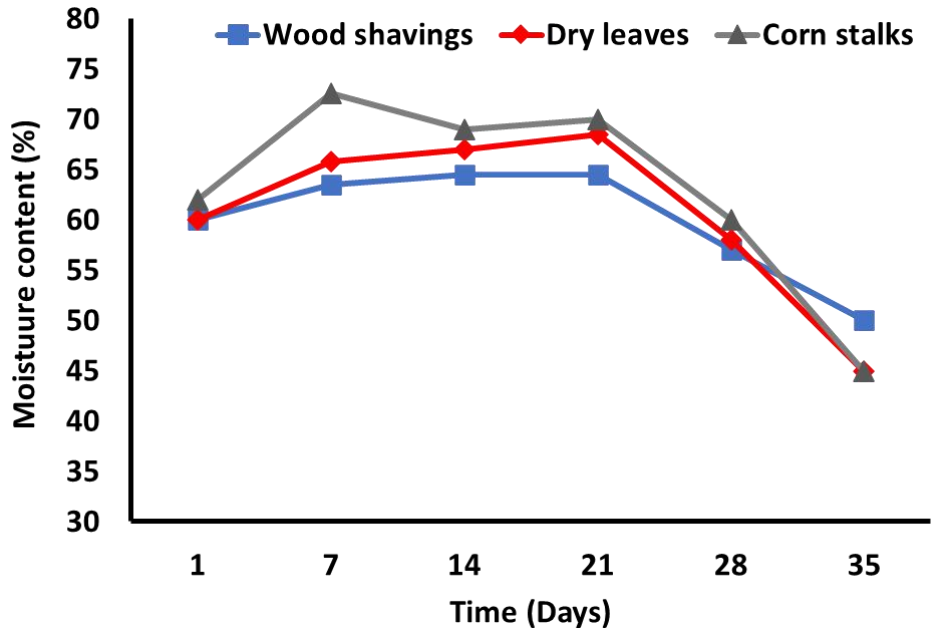


Figure 4. 5 Variation in moisture content in compost for different bulking agents

Evaluation of Maturity of Compost

C/N Ratio of Compost for Different Bulking Agents

The C/N (Carbon to Nitrogen) ratio is considered one of the most important parameters and indicators for the assessment of the composting process. The reduction in the C/N ratio defines the efficiency of the composting process, reflecting the immediate utilization of nitrogenous and carbonaceous organic substrate (Song et al., 2021). Adjusting the ratio of waste to bulking agent is necessary to assess the carbon and nitrogen content of the compost. When the C/N ratio is high, it increases the maturation phase, and when it is lower it results in rapid loss of nitrogen through runoff and volatilization. The optimum C/N ratio for the final and stable compost is 14–18, indicating a gradual nitrogen mineralization when being applied to the soil (Zahra et al., 2023).

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

The ratio of waste and bulking agents was adjusted to assess the carbon-to-nitrogen content of the compost before starting the composting process. The C/N ratio in this study was within the value of 25-35 w/w to start an effective composting process as recommended by studies conducted in the past. The C/N ratio for compost with wood shavings at the start of composting was 33, for compost with dry leaves was 25, and for compost with corn stalks was 29. The final C/N ratio for all three reactors was less than and equal to 20, which is considered an ideal value and indicator of stable and final compost (Song et al., 2021). The graphical rrepresentation of the C/N ratio of compost

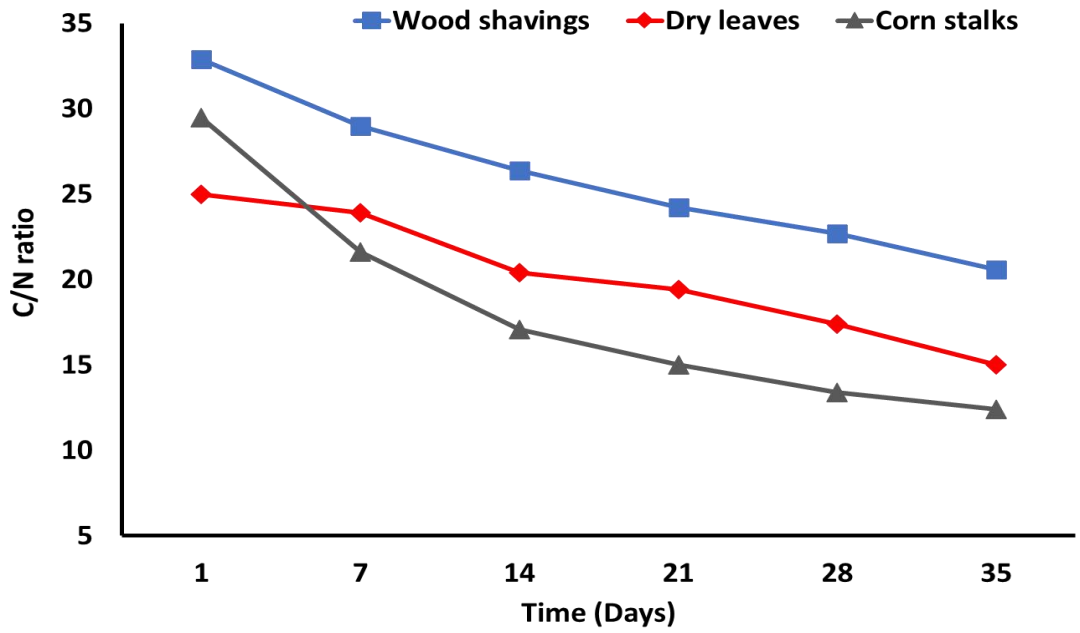


Figure 4. 7 Variation in C/N ratio of compost for different bulking agents

with three bulking agents in three different reactors is given below in **Figure 4.7.**

Total Kjeldahl Nitrogen (TKN) Of Compost For Different Bulking Agents

Total nitrogen showed an initial rise in all reactors during the initial four weeks and continued to increase til week 6. As per past studies, the elevation in total nitrogen levels may be due to the dry mass loss from emissions associated with CO_2, water loss through evaporation, and the activity of nitrogen-fixing bacteria (Hashim et al., 2022). Other studies also indicate that the increase in the TKN values throughout the composting process might be due to the concentration effect resulting from the degradation of organic matter, which results in weight loss. Additionally, the nitrogen-fixing bacteria's involvement could also contribute to a rise in the concentration of nitrogen (Ameen &

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

Dohuki, 2022).

The graph presented below in **Figure 4.8** shows the weekly increase in the overall nitrogen content, attaining its peak at week 6 in all three reactors. Maximum concentrations of the TKN values were observed in the last week of composting, indicating a potential contribution of the nitrogen-fixing bacteria during the advanced stages of the composting process. It was also observed that compost with dry leaves and corn stalks as bulking agents have higher TKN values throughout the composting process than the compost with wood shavings. The reason behind this is that wood shavings have a higher amount of lignin and cellulose content which degrade comparatively slowly than the other 2 bulking agents that were used in this study (Ameen & Dohuki, 2022).

Total Phosphorus In Compost For Different Bulking Agents

The collective phosphorus concentration in the compost pile experiences a gradual increase week by week. As shown in the graphs given below, the total phosphorus content in each of the three reactors—compost with wood shavings (WS), compost with dry leaves (DL), and compost with corn stalks (CS)—gradually increases throughout the composting process. The highest concentration was observed in the final week, as compared to the lowest levels were observed in the initial phases. The Concentrations of phosphorus fluctuate between 0.03% and 0.24%.

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

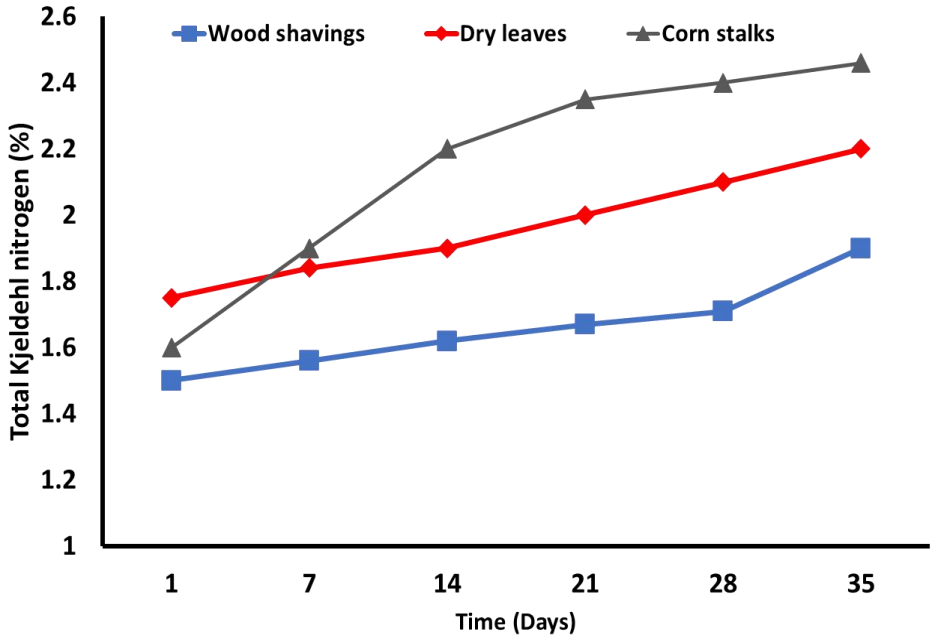


Figure 4. 8 Variation in Total Kjeldahl nitrogen in compost for different bulking agents

The variation in total phosphorus present in compost for different bulking agents over the period of six weeks is shown below in **Figure 4.9.**

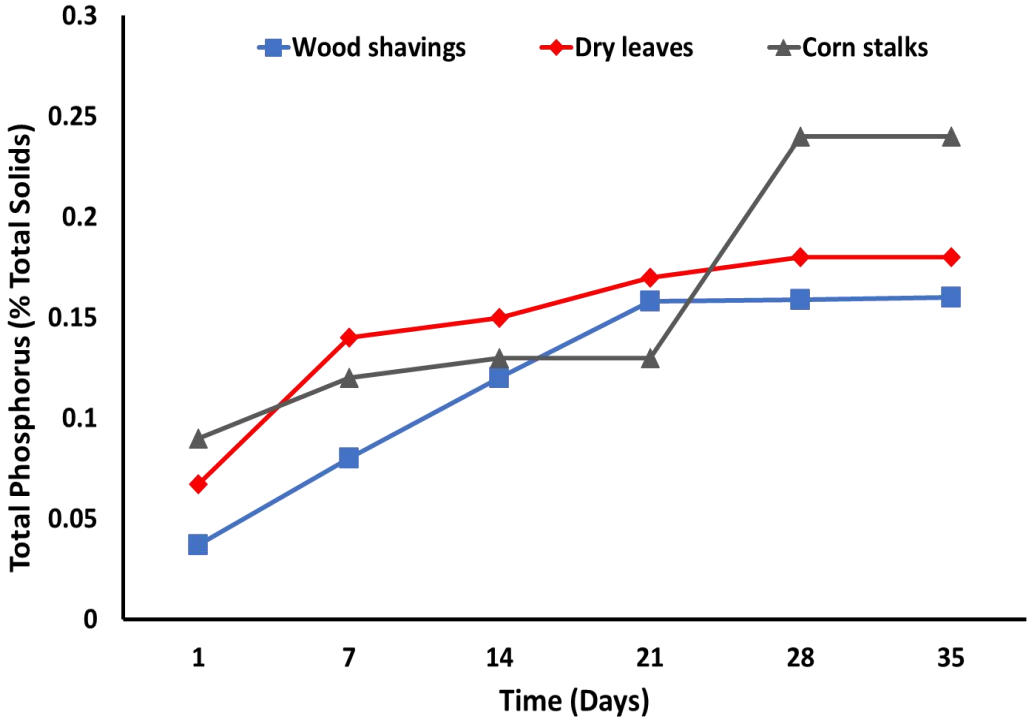


Figure 4. 9 Variation in total phosphorus in compost for different bulking agents

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

The elevation in total phosphorus content during composting may be attributed to a concentration effect induced by the accelerated rate of carbon loss associated with the decomposition of organic materials (Hashim et al., 2022). Other studies also suggested that the rise in the concentration of phosphorus is linked to the reduction in compost volume and the concurrent increase in pile bulk density (Al-Nawaiseh et al., 2021b).

Compost Management From GHG Emissions Perspective

The second objective of this study was to mitigate the GHG emissions that are linked with MSW (municipal solid waste) by converting organic part of the municipal waste into a mature and stable compost. GHG emission potential of compost was calculated at different stages of compost formation using different bulking agents. A comparison was made, of the different compost formation options such as compost with wood shaving, dry leaves, and cornstalks as bulking agents with regards to GHG emission was then made possible. The results regarding this have been presented and discussed in this section.

Methane Emission Potential Of Compost Mixture For Different Bulking Agents

The GHG emissions potential of final and mature compost was estimated by using the equation that is given in section 3.4.1.1. and compared with the organic fraction of municipal solid waste before starting the composting process (Gunamantha & Sarto., 2012). When we compare the GHG emissions potential of mature compost that is 901 CH_4 gCO_2 eq in case of compost with wood shavings 791 CH_4 gCO_2 eq in case of compost with dry leaves and 690 CH_4 gCO_2 eq in case of compost with corn stalks with that of OFMSW before starting the composting process, it was very high, that is 3045 CH_4 gCO_2 eq in case OFMSW with wood shavings 2840 CH_4 g CO_2 eq in case of OFMSW with dry leaves and 2763 CH_4 gCO_2 eq in case of OFMSW with corn stalks. Thus, with composting under aerobic conditions by using different bulking agents, the GHG emission potential of OFMSW decreases by about 70% in the case of compost with wood shavings, 72% in the case of compost with dry leaves, and 75 % in the case of compost with corn stalks. GHG emissions potential of OFMSW at the initial stage of compost VS matured compost in the case of Methane (CH_4) is shown below in **Figure 4.10.**

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

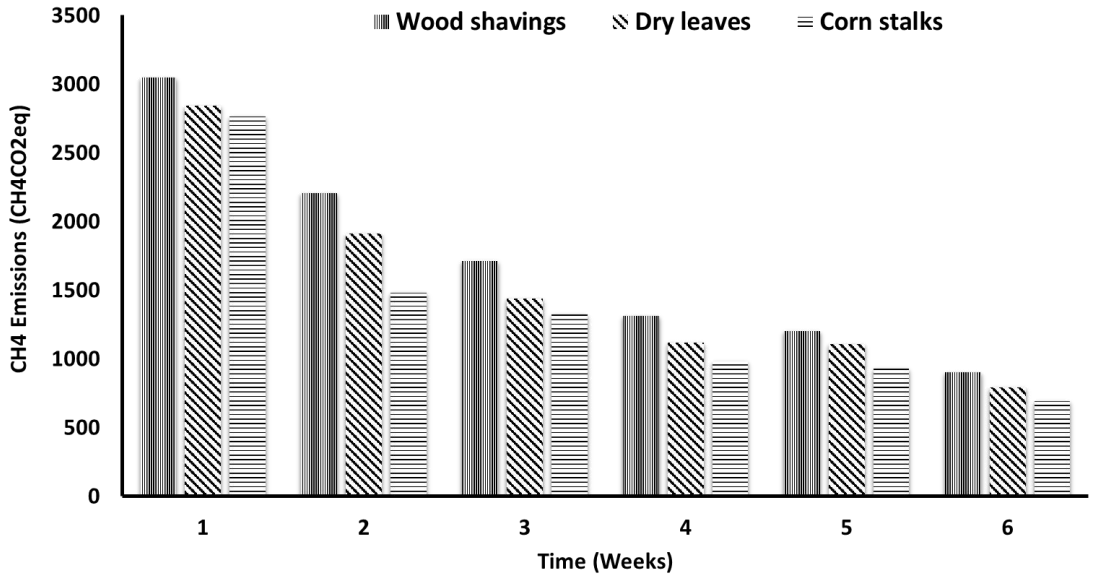


Figure 4. 10 Methane emission potential of compost mixture for different bulking agents

Nitrous Oxide Emission Potential Of Compost Mixture For Different Bulking Agents

The amount of nitrous oxide that is to be emitted from three different types of compost using different bulking agents was calculated, the details of which are given in section 3.4.1.2. of chapter 3. After that these emission potentials were compared with the organic fraction of municipal solid waste before starting the composting process. When we compare the N_2O emission potentials of mature compost, they were 33, 41 and 46 gCO_2 eq/kg compost for wood shavings, dry leaves, and corn stalks respectively with that of OFMSW before starting the composting process, they were very high, 70, 86, 70 gCO_2 eq/kg compost for OFMSW with wood shavings, dry leaves and corn stalks respectively. Thus, with composting under aerobic conditions by using different bulking agents, the N_2O emissions were reduced by about 53%, 52 %, 34 % for wood shavings, dry leaves, and corn stalks respectively (Zeshan & Visvanathan, 2014). GHG emissions potential of OFMSW at the initial stage of compost VS matured compost in the case of N_2O is shown below in **Figure 4.11.**

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Cumulative GHG Emission Potential of Compost Mixture for Different Bulking Agents

The cumulative GHG emissions at different stages of compost formation were calculated. If we look at the cumulative GHG potential of compost in **Table 4.2**, it is observed that in GHG Emissions potential of OFMSW decreases by 70% in the case of composting with wood shavings, 71% in case of dry leaves and 74% in case of cornstalks (Møller et al., 2009).

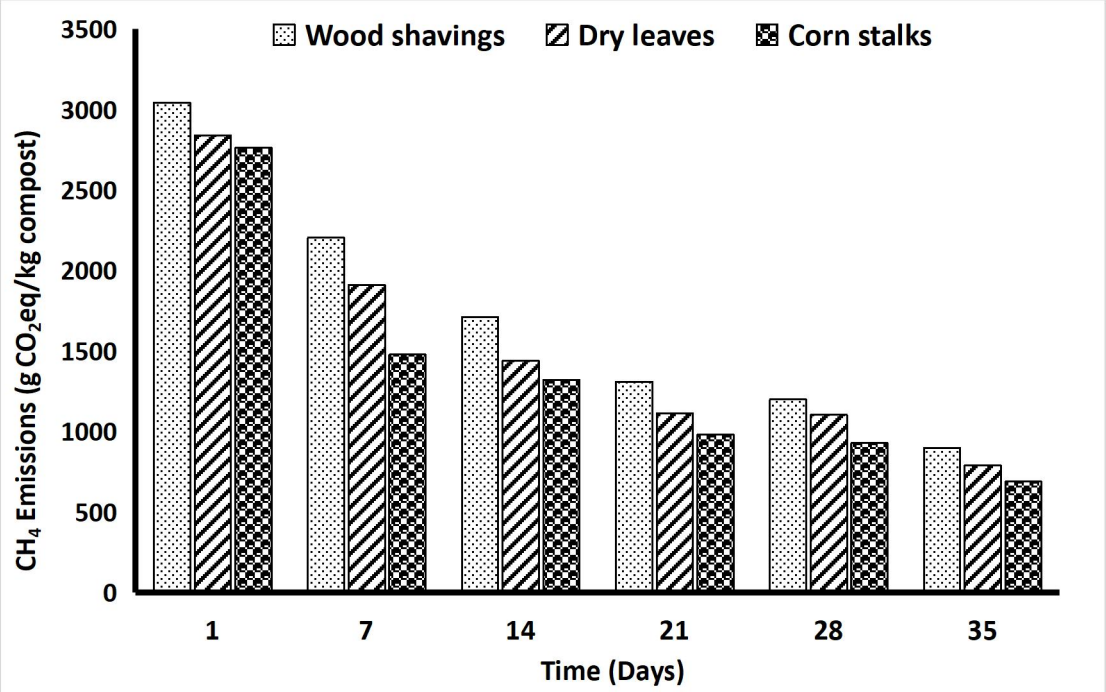


Figure 4. 11 Nitrous oxide emission potential of compost mixture for different bulking agents

Table 4. 2 Loss of GHG emission potential of compost mixture over time

Days	Wood shavings	Dry leaves	Corn stalks
	(gCO_2eq/kg compost)		
1	3114.7	2926	2833
7	2261	1971	1530
14	1762	1491	1380
21	1351	1163	1034
28	1240	1149	979

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

35	934	832	736

Emissions Avoided By Land Application Of Compost (Nitrogen & Phosphorus)

The second part of second objective was how GHG will be avoided by land application of compost. That means by applying compost to soil we can avoid the GHG emissions of fossil carbon by energy use for production of chemical fertilizer. In this study the N and P act as nutrients provided by the land applied compost is the most important factor, which replaces the use of chemical fertilizer and hence the GHG from fertilizer manufacturing is avoided (Brown et al., 2010). The **Figures 4.12 & 4.13** presented below shows the GHG emissions avoided by land application of compost.

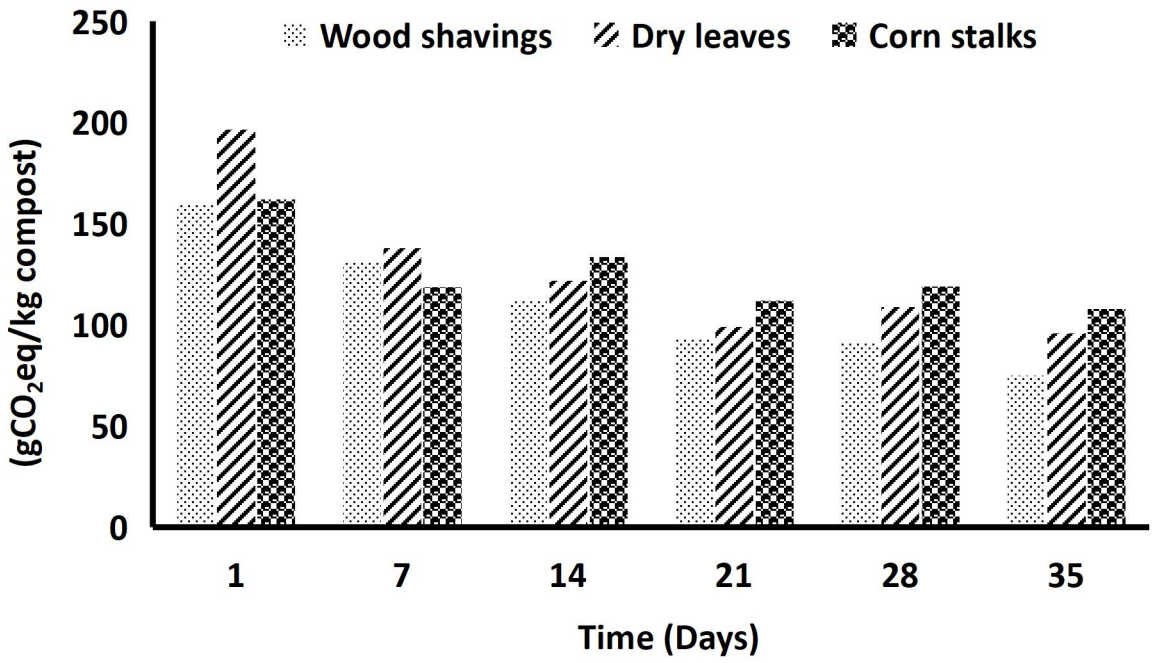


Figure 4. 12 Emissions avoided by land application of compost (Nitrogen)

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 8 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

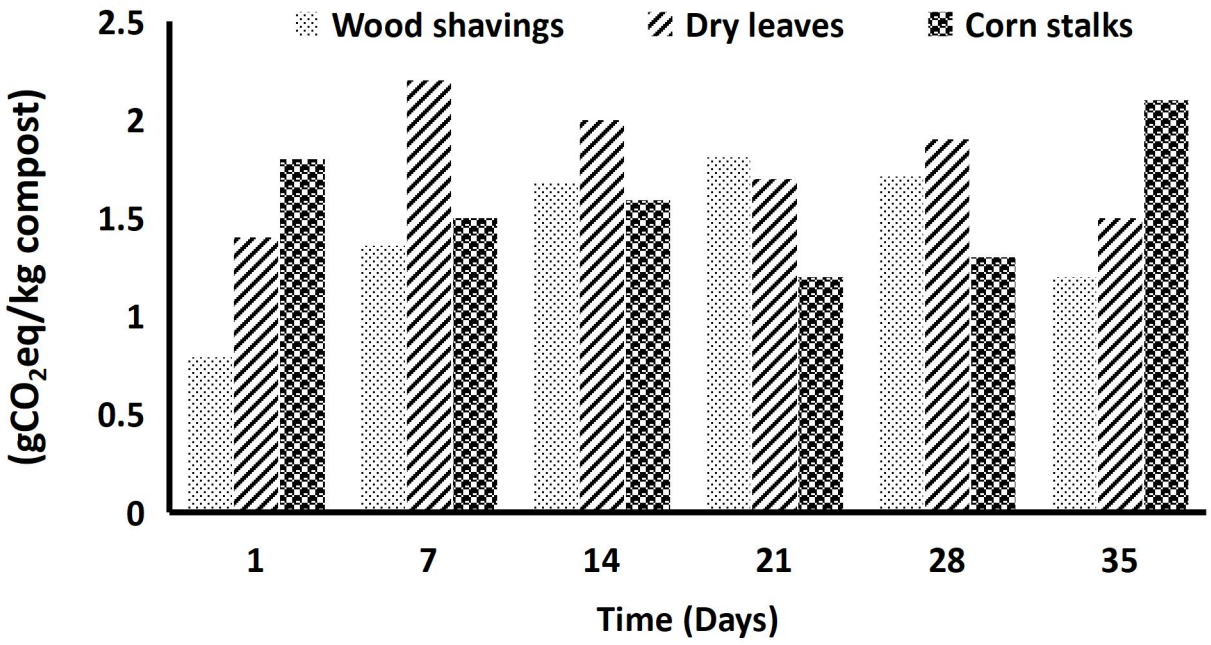


Figure 4. 13 Emissions avoided by land application of compost (Phosphorus)

Conclusions And Recommendations

Conclusion presents a summary of the research findings together with specific recommendations. The objective is to offer useful advice for enhancing composting procedures and raising the general efficacy of waste management systems

Conclusions

The C/N ratio results indicate that composting organic fraction of municipal solid waste with three bulking agents has produced mature and stable compost. Results of GHG emissions from compost show that raw waste has the maximum GHG potential and should not be dumped and landfilled as its dumping contributes the most `to GHG emissions. Results also indicate that the results were almost similar for all the three bulking agents. The C/N ratio was 20, 15, and 12.4 for compost with wood shavings, dry leaves, and corn stalks respectively, which shows that dry leaves and corn stalks formed more stable compost than wood shavings as bulking agents. As far as GHG potential is concerned, all three bulking agents showed maximum reduction as compared to raw waste that had maximum Greenhous potential. Composting waste has the potential to significantly reduce GHG emissions, with reductions of 70%, 71%, and 74% observed for

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

wood shavings, dry leaves, and corn stalks, respectively. So, all the three bulking agents proved beneficial for composting,

Recommendations

The organic fraction of municipal solid waste has the maximum GHG emission potential and should not be dumped or landfilled as its dumping contributes the most to GHG emissions. The co-composting of waste with sludge and manure could be investigated for future studies. The effect of macronutrients other than (nitrogen, and phosphorus) and micronutrients should also be investigated for future studies.

References

Adhikari, B. K., Barrington, S., Martinez, J., & King, S. (2008). Characterization of food waste and bulking agents for composting. Waste Management, 28(5), 795–804. https://doi.org/10.1016/j.wasman.2007.08.018

Awasthi, M. K., Pandey, A. K., Bundela, P. S., & Khan, J. (2015). Co-composting of organic fraction of municipal solid waste mixed with different bulking waste: Characterization of physicochemical parameters and microbial enzymatic dynamic. Bioresource Technology, 182, 200–207. https://doi.org/10.1016/j.biortech.2015.01.104

Al-Nawaiseh, A. R., Aljbour, S. H., Al-Hamaiedeh, H., El-Hasan, T., Hemidat, S., & Nassour, A. (2021a). Composting of Organic Waste: A Sustainable Alternative Solution for Solid Waste Management in Jordan. In Jordan Journal of Civil Engineering (Vol. 15, Issue 3).

Al-Nawaiseh, A. R., Aljbour, S. H., Al-Hamaiedeh, H., El-Hasan, T., Hemidat, S., & Nassour, A. (2021b). Composting of Organic Waste: A Sustainable Alternative Solution for Solid Waste Management in Jordan. In Jordan Journal of Civil Engineering (Vol. 15, Issue 3).

Ameen, H. A., & Dohuki, M. S. S. M. (2022). The effect of leaching and bulking agents on the quality of municipal solid waste compost. Environmental Technology (United Kingdom). https://doi.org/10.1080/09593330.2022.2101026

Brown, S., Beecher, N., & Carpenter, A. (2010). Calculator tool for determining greenhouse gas emissions for biosolids processing and end use. Environmental Science & Technology, 44(24), 9509–9515. https://doi.org/10.1021/es101210k

Guo, H. nan, Liu, H. tao, & Wu, S. (2022). Immobilization pathways of heavy metals in

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

composting: Interactions of microbial community and functional gene under varying C/N ratios and bulking agents. Journal of Hazardous Materials, 426(August 2021), 128103. https://doi.org/10.1016/j.jhazmat.2021.128103

Guidoni, L. L. C., Marques, R. V., Moncks, R. B., Botelho, F. T., Da Paz, M. F., Corrêa, L. B., & Corrêa, É. K. (2018). Home composting using different ratios of bulking agent to food waste. Journal of Environmental Management, 207, 141–150. https://doi.org/10.1016/j.jenvman.2017.11.031

Gunamantha, M., & Sarto. (2012). Life cycle assessment of municipal solid waste treatment to energy options: Case study of Kartamantul region, Yogyakarta. Renewable Energy, 41, 277–284. https://doi.org/10.1016/j.renene.2011.11.008

Hashim, S., Waqas, M., Rudra, R. P., Khan, A. A., Mirani, A. A., Sultan, T., Ehsan, F., Abid, M., & Saifullah, M. (2022). On-Farm Composting of Agricultural Waste Materials for Sustainable Agriculture in Pakistan. Scientifica, 2022. https://doi.org/10.1155/2022/5831832

Khalid, S., Ullah Malik, A., Irfan Ullah, M., Shaque Khalid, M., Muhammad Rashad Javeed, H., & Asif Naeem, M. (2022). Food waste: causes and economic losses estimation at household level in Pakistan. Environmental Science and Pollution Research, 0123456789. https://doi.org/10.1007/s11356-023-28775-4

Khatri, K. L., Muhammad, A. R., Soomro, S. A., Tunio, N. A., & Ali, M. M. (2021). Investigation of possible solid waste power potential for distributed generation development to overcome the power crises of Karachi city. Renewable and Sustainable Energy Reviews, 143(October 2020), 110882. https://doi.org/10.1016/j.rser.2021.110882

Kumar, M., Ou, Y. L., & Lin, J. G. (2010). Co-composting of green waste and food waste at low C/N ratio. Waste Management, 30(4), 602–609. https://doi.org/10.1016/j.wasman.2009.11.023

Lee, J., Luyima, D., Lee, C., Park, S., & Oh, T. (2020). Efficiencies of unconventional bulking agents in composting food waste in Korea. Applied Biological Chemistry, 63(1). https://doi.org/10.1186/s13765-020-00554-6

Li, D., Kumar, R., Johnravindar, D., Luo, L., Zhao, J., & Manu, M. K. (2022). Effect of different-sized bulking agents on nitrification process during food waste digestate

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

composting. Environmental Technology (United Kingdom), 1–11. https://doi.org/10.1080/09593330.2022.2161950

Manu, M., Kumar, R., & Garg, A. (2019). Decentralized composting of household wet biodegradable waste in plastic drums: Effect of waste turning, microbial inoculum and bulking agent on product quality. Journal of Cleaner Production, 226, 233–241. https://doi.org/10.1016/j.jclepro.2019.03.350

Maeda, K. (2020). Use of corn stover as bulking agent in dairy manure composting toward Japanese circular dairy farming. PLoS ONE, 15(10), e0241064. https://doi.org/10.1371/journal.pone.0241064

Michel Devadoss, P. S., Pariatamby, A., Bhatti, M. S., Chenayah, S., & Shahul Hamid, F. (2021). Strategies for reducing greenhouse gas emissions from municipal solid waste management in Pakistan. Waste Management and Research, 39(7), 914–927. https://doi.org/10.1177/0734242X20983927

Møller, J., Boldrin, A., & Christensen, T. H. (2009). Anaerobic digestion and digestate use: accounting of greenhouse gases and global warming contribution. Waste Management & Research the Journal for a Sustainable Circular Economy, 27(8), 813–824. https://doi.org/10.1177/0734242x09344876

Peng, L., Ma, R., Jiang, S., Luo, W., Li, Y., Wang, G., Xu, Z., Wang, Y., Qi, C., Li, Y., Li, G., & Yuan, J. (2022). Co-composting of kitchen waste with agriculture and forestry residues and characteristics of compost with different particle size: An industrial scale case study. Waste Management, 149, 313–322. https://doi.org/10.1016/j.wasman.2022.06.029

Sohoo, I., Ritzkowski, M., Heerenklage, J., & Kuchta, K. (2021). Biochemical methane potential assessment of municipal solid waste generated in Asian cities: A case study of Karachi, Pakistan. Renewable and Sustainable Energy Reviews, 135(June 2020). https://doi.org/10.1016/j.rser.2020.110175

Song, B., Manu, M., Li, D., Wang, C., Varjani, S., Ladumor, N., Michael, L., Xu, Y., & Wong, J. W. (2021). Food waste digestate composting: Feedstock optimization with sawdust and mature compost. Bioresource Technology, 341, 125759. https://doi.org/10.1016/j.biortech.2021.125759

Verma, S., Awasthi, M. K., Liu, T., Awasthi, S. K., Yadav, V., Ravindran, B., Syed, A.,

Online ISSN 3007-3197
Print ISSN 3007-3189

Eswaramoorthy, R., & Zhang, Z. (2023). Biochar as smart organic catalyst to regulate bacterial dynamics during food waste composting. Bioresource Technology, 373, 128745. https://doi.org/10.1016/j.biortech.2023.128745

Wang, Y., Tang, Y., Li, M., & Yuan, Z. (2021). Aeration rate improves the compost quality of food waste and promotes the decomposition of toxic materials in leachate by changing the bacterial community. Bioresource Technology, 340(July), 125716. https://doi.org/10.1016/j.biortech.2021.125716

Xiao, Y., Zeng, G. M., Yang, Z. H., Shi, W. J., Huang, C., Fan, C. Z., & Xu, Z. Y. (2009). Continuous thermophilic composting (CTC) for rapid biodegradation and maturation of organic municipal solid waste. Bioresource Technology, 100(20), 4807–4813. https://doi.org/10.1016/j.biortech.2009.05.013

Xu, Z., Xu, W., Zhang, L., Ma, Y., Li, Y., Li, G., Nghiem, L. D., & Luo, W. (2021). Bacterial dynamics and functions driven by bulking agents to mitigate gaseous emissions in kitchen waste composting. Bioresource Technology, 332(March). https://doi.org/10.1016/j.biortech.2021.125028

Zahra, K., Farhan, M., Kanwal, A., Sharif, F., Hayyat, M. U., Shahzad, L., & Ghafoor, G. Z. (2023). Investigating the role of bulking agents in compost maturity. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-41891-y

Zeng, J., Yin, H., Shen, X., Liu, N., Ge, J., Han, L., & Huang, G. (2018). Effect of aeration interval on oxygen consumption and GHG emission during pig manure composting. Bioresource Technology, 250(November 2017), 214–220. https://doi.org/10.1016/j.biortech.2017.11.010

Zeshan, & Visvanathan, C. (2014). Evaluation of anaerobic digestate for greenhouse gas emissions at various stages of its management. International Biodeterioration and Biodegradation, 95(PA), 167–175. https://doi.org/10.1016/j.ibiod.2014.06.020

Zhu, L., Zhao, Y., Yao, X., Zhou, M., Li, W., Liu, Z., & Hu, B. (2023). Inoculation enhances directional humification by increasing microbial interaction intensity in food waste composting. Chemosphere, 322(November 2022), 138191. https://doi.org/10.1016/j.chemosphere.2023.138191