Composting

Subjects: Agricultural Engineering
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Composting is the most adaptable and fruitful method for managing biodegradable solid wastes; it is a crucial agricultural practice that contributes to recycling farm and agricultural wastes. Composting is profitable for various plant, animal, and synthetic wastes, from residential bins to large corporations. Composting and agricultural waste management (AWM) practices flourish in developing countries, especially Pakistan.

Keywords: composting ; biodegradability ; decomposing ; organic waste

1. Introduction

Composting is the biological conversion of the solid waste of plant and animal organic materials into a fertile matrix through numerous micro-organisms, including actinomycetes, bacteria, and fungi, in the presence of oxygen. The addition of diverse microorganism in a solid waste can convert it into compost or many by-products, .g., heat, water, and CO_2 [1][2]. Humus is the solid and stable matrix after the microbiological process that can be usefully applied to land as an organic fertilizer to increase the fertility and structure of the soil. In ancient history, i.e., pre-Columbian Indians of Amazonia or ancient Egyptians and numerous prehistoric cultures used composting as a primitive technique for the betterment of soil. In the previous four decades, the composting technique has flourished, and its beneficial impact is illustrated with scientific research. The vulnerability and interconnection of various competing factors regarding the knowledge and process engineering of a composting matrix have been established [3][4][5].

Composting innovative processes were developed and employed by large- or medium-scale farmers, but they are expensive for small-scale farmers because the techniques require high-tech equipment for composting. Despite discrete processes/techniques, the crucial key points of the composting processes were indistinguishable each time, like natural, chemical, and physical characteristics. Appropriateness of distinctive input supplies and alterations and their fitting structure, substrate degradability, dampness management, energy, porosity, air space, energy adjustment, deterioration, and stabilization are needed to study and distinguish compost and composting processes [3][6].

2. Composting Stages

Composting processes undergo four stages: mesophilic, thermophilic, cooling, and finally ending with compost maturation; these stages can happen concomitantly rather than consequently [7] (Figure 2). Each stage duration depends on the mixture's inceptive framework, water content, air circulation, and microbiological composition [8][9]. During the mesophilic phase, a combination of bacteria, fungi, and actinomycetes induce the rapid metabolism of C-abundant substrates. Moreover, this is accomplished by selecting tolerable temperatures, generally within 15–40 °C, because aerobic metabolism will produce heat. Transforming the matter and air circulation decreases the temperature, for the time being, reducing the rapid decay of other organic matter. Thus, the temperature rises once again, as shown in **Figure 1**. In the thermophilic phase (2nd stage), temperature increases to around 40 °C, favoring mostly thermophilic bacteria, e.g., bacillus. When C compounds are produced after substrate reduction, a modest temperature fall occurs followed by the cooling phase.

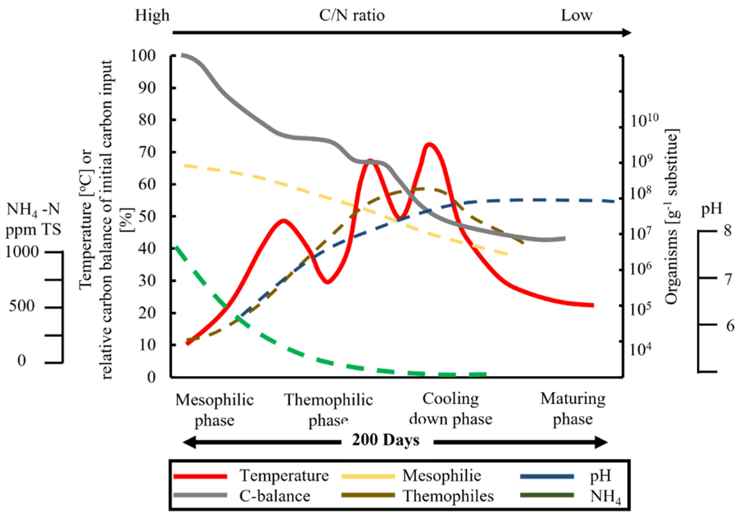

Figure 1. Time, temperature, the progression of compost biota, and further processes during discrete stages in composting.

Fungi break down more complex structures and more resistant components like lignin and cellulose molecules. Additionally, actinomycetes play a crucial role in forming humic compounds via condensation processes and breakdown [9]. Using aerobic bacteria, the final composting maturity is characterized by lower oxygen uptake rates and temperatures < 25 °C. During this final phase, the breakdown of various organic components continues, and macrofauna and soil organisms enter. By metabolizing phytotoxic chemicals, the organisms of this phase have a favorable effect on compost maturation, e.g., plant disease suppression [10].

Consequently, compost quality improves primarily during maturation (final stage) [11]. The final product of composting is characterized by pH and a lower C/N ratio of 15 to 20 compared to the initial substrate composition. It may contain a significant amount of plant-available NO_3^-, but NO_4^+ levels are low. Moreover, the intensity of the compost odor is significantly diminished [12]. However, it appears that the OM has stabilized, retaining recalcitrant C compounds [9]. **Table 1** explains the favorable and sustainable application of different crop residues' influence on numerous biological, chemical, and physical aspects during the different processes. The outcomes showed which method is best with respect to input residues and the desired output products.

3. Discrete Waste Composting

In contrast to landfilling, which elevates the pollution risk for groundwater, discrete waste composting techniques are environment friendly and avoid groundwater contamination since chemical pollutants and bacteria are reduced during composting. Composting permits persistent organic pollutants and endocrine disruptors to remain in the soil while beneficial bacteria break down the toxins. The elimination of these harmful chemicals has not been simple. Although numerous methods have been attempted to eradicate them, there is no agreed success rate. A thorough application can increase agricultural and environmental sustainability. It also improves soil OM content and enhances agricultural productivity [13] due to the availability of plant-growth-promoting organisms and sufficient nutrients in the composted debris [14] and significantly contributes to the certification of food safety. Compost is helpful for bioremediation [15], weed control [16], plant disease control [17], pollution anticipation [18], and erosion management, in addition to its use as fertilizer. Composting also increases soil biodiversity and reduces environmental risks associated with synthetic fertilizers [19].

Composting is a fundamental aspect of a comprehensive AWM strategy. The key strategy for practical integrated AWM is nutrition level improvement. Compost is rich in essential plant nutrients, e.g., nitrogen (N), phosphorus (P), potassium (K), sulfur (S), carbon (C), and magnesium (Mg), as well as various essential trace elements [10][20]. Consequently, compost can be described as an assortment of nutrient-rich organic fertilizers [21]. Compost processing parameters and organic feedstocks determine its key chemical features, e.g., C/N ratio and pH, as well as the content of other nutrients (**Table 2**). Total N, P, and K levels could contribute to soil fertility when used as soil amendment agents. By adequately combining these organic components, nutrient-rich compost substrates can be produced and used in agriculture in place of commercial mineral fertilizers. This aspect is discussed in the following subsections.

- Crop residue waste

Global agricultural waste production is substantial, and crop leftover management is imperative [22]. In addition, waste disposal pollution necessitates research into eco-friendly methods for managing agricultural wastes as the increase in agricultural waste exacerbates aesthetic, health, and environmental issues. Consequently, research into secure disposal methods is necessary. Composting has evolved into an eco-friendly, cost-effective, and secure treatment technology; it is a productive method for intensifying and preserving agricultural products [23]. Biodegradable wastes, e.g., wood shavings, pine needles, dry leaves, sawdust, and coir pith, are commingled to maintain appropriate and durable humus [24]. However, lignin-rich plant products are difficult to decompose. Lime is used to accelerate the breakdown process in the garbage. These components are mixed at a ratio of 5 kg (lime) per 1000 kg (plant materials) to produce high-quality compost. Lime mixed with water may result in the formation of a semi-solid substance or a dry powder. Lime boosts humification of plant wastes by decreasing lignin structure and improving humus content [25]. Likewise, usable compost substrates can be generated from various crop leftovers using a suitable process and quality control procedures (**Table 1**).

- Municipal solid waste (MSW)

Increasing population, industrialization, and urbanization has elevated the levels of MSW, which has become a problematic responsibility in Pakistan and worldwide [26].

The most well-known biodegradable waste procedures are microbiological stabilization and composting [27]. Due to the high organic content of MSW, composting is theoretically one of the most suitable AWM technologies for MSW management [28][29][30]. In addition, it generates a soil layer known as a conditioner with agronomic benefits, and is an economically viable and valuable method for offsetting the organic part of the trash. It also reduces the disposed waste, remarkably decreasing the residual waste's pollution capacity and volume for landfilling. As a result, numerous developing Asian countries are turning to compost to manage their MSW. Picking, contaminant separation, sizing and mixing, biological decomposition, and other functions are all part of the modern MSW management composting system. **Figure 2** shows the schematic flow diagram of the distinct method of MSW management from source to utmost disposal. To weigh Pakistan's Lahore compost waste intake, a weighbridge having a capacity of 75 tons is located at the Mahmood Booti open dumping site operated by the City District Government of Lahore [31]. Composting is primarily a small-scale industry in Bangladesh and the Maldives. MSW composting in Indore and a large-scale aerobic device in Mumbai were installed in India in 1994 to control 500 metric tons of MSW [29]. These are the two examples of operational large-scale composting ingenuities in India [32]. By 2008, composting had been used to treat 9% of India's MSW [29]. The average cost ranged from $25 to $30 per ton, while the market value per metric ton ranged from $33.5 to $42. India intends to add other plants in near future [33].

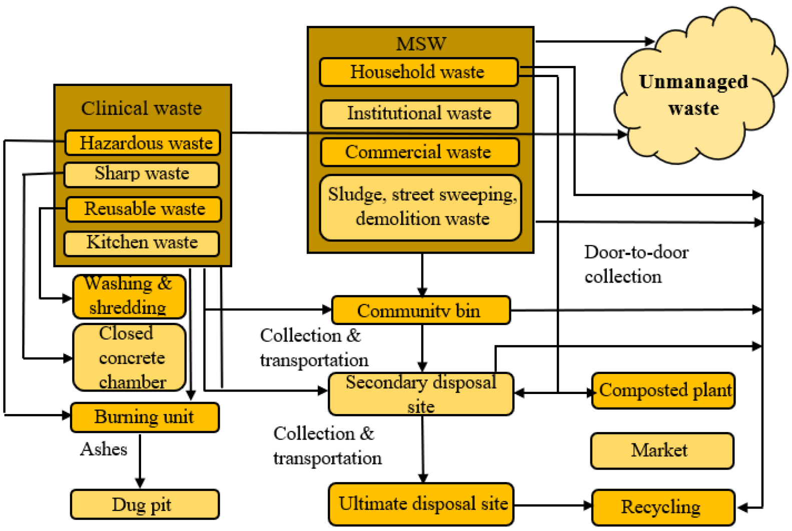

Figure 2. Schematic flow diagram of MSW management by composting.

- Biomedical waste (BMW)

The waste produced through the diagnosis, immunization, and treatment of human beings, research practices, and animal is organic BMW. In Pakistan, hospitals make approximately 2.07 kg of BMW per bed per day [34]. If BMW is not managed properly, it may cause serious environmental and health issues [35]. Therefore, safe disposal techniques need to be investigated, and composting is a sustainable option. Neem and tobacco extracts are commercially cost-effective for local small farmers and provide the best degradation of organic BMW. Thus, these extracts can be employed for conversion of organic BMW into potential fertilizer [36]. Previous research revealed that the BMW must be similarly treated with 5% sodium hypochlorite (NaOCl) at the disposal location [37]. It can be exposed to an initial decomposition process by mixing it with cow dung slurry, and then VC can be utilized to treat it further. Several epigeal species of worms may be used for this purpose. By using this approach to handle BMWs, these worms are more effective in decomposition. VC and proper handling of BMW can be energy-efficient and sustainable methods of eliminating and recycling this hazardous waste [37]. Meanwhile, the composting processes of various wastes come in discrete modes. The most utilized techniques are conventional composting, i.e., AC, AnC, and VC, and emerging composting, e.g., two-stage composting, as described below.

Table 1. Treatment methodologies of different types of crop residues.

Waste	Physicochemical Characteristics	Method	Quality Control	Final Products and Uses	Outcomes	References
Barley waste	Composting in an open-air pile that was rotated 7 times in 105 d. Average temperatures of 65–68 °C with relative humidity of 45–65%.	Maximum temperatures of 65–68 °C with humidity of 45–65%.	Composting	Fertilizer	Micronutrient absorption favored at lowest doses. Doses >10 mg/L inhibited it and depressed growth at highest levels.	[38]
Barley straw waste	Conductance (compost to water, *w*/*w*: 1:3). pH (in water and 0.01 M CaCl) Quality of dry matter (% fw, 105 °C) Ash content (% dw, 480 °C/16 h) in triplicate.	Heterotrophic mesophilic bacteria.	Composting	Composting of cow and swine waste with barley straw.	1—C/N ratio declined from 22.6–28.5 to 12.7 during composting. 2—Approximately 11–27% and 13–23% of total C and N were lost after 7 d of intensive composting and 62–66% and 23–37% for whole composting, respectively.	[39]
Barley waste	Final compost pH was 8.7 and C/N ratio was 13. No. of seeds germinated in co-compost depending on grains used.	Total OM was estimated by weight loss on ignition at 540 °C/16 h, and moisture on drying at 105 °C/24 h.	1—Composting 2—VverC	OM composition was high in barley wastes and solid poultry manure.	OM content of barley waste was high (86.3% dw) and had N deficiency.	[40]
Wheat straw waste	Compost contributed 10% of its total N for plant growth during growing season.	During growing season, compost supplied 10% of available N to plants.	1—Mature composting 2—Immature composting	Additional fertilizer	1—At 126.5 h, total H yield of 68.1 mL H/g TVS was 136-fold higher than raw wheat straw wastes. 2—Substrate pretreatment was essential in turning wheat straw wastes into biohydrogen by composts producing hydrogen.	[41]
Rice straw	Lowest C/N ratios found (17–24). Pathogenic micro-organisms were extracted from rice straw by heating at 62 °C/48 h.	Micro-organisms respiration behavior was determined on separate initial C/N (17, 24, and 40) raw materials.	Composting	Development of paper, building materials, soil incorporation, manure, energy supply, and animal feed.	Rice straw residues was rich in OM (80%), oxidizable organic C (34%), and C/N ratio (very volatile and average of 50), suggesting a potential C supply for micro-organisms that can tolerate composting conditions.	[42]

Waste	Physicochemical Characteristics	Method	Quality Control	Final Products and Uses	Outcomes	References
Wheat straw waste	Overall C and N of materials was estimated. Wheat straw has C/N ratio of 100 and cover-grass hay has C/N ratio of 15.	Weight loss of compost samples oven-dried at 80 °C/24 h to assess water content.	1—C1-Automatic NC analyzer connected to isotope mass spectrometer measured total N and C. 2—NH_4 and NO analysis—Traditional calorimetric approaches of flow-injection analysis.	Fertilizer	1—pH ranged 7.6–8.9, with highest values after 3–4 weeks. 2—Weight loss after weeks of composting reduced by 44–45% of original weight. 3—After 7 1/2 weeks, weight loss was 61–63% of actual weight. 4—4% N rose from 2.8 to 4.6%.	[43]
Wheat straw waste	pH = 6.9 Negligible $CaCO_3$ content Organic C content of 11.0 g C/kg dry soil	Three types of UWC were applied 1—Bio-waste compost (BIO) from green waste and source-separated organic fraction. 2—Co-compost from mixture of 70% green waste and 30% sewage sludge. 3—Municipal solid waste compost.	1—CERES model 2—Parameter modelling	Soil conditioner or fertilizer	1—Simulated N fluxes indicated that organic amendments resulted in additional leaching of up to 8 kg N/ha/year. 2—After many years, composts mineralized 3–8% of their original organic N content. Composts with slower N release delivered more N to crops. 3—CERES used to help choose best time to apply compost.	[44]
Rice flakes	pH = 7	Aspergillus spp.	Composting	Edible products	1—As opposed to inorganic N, organic N contributed to higher enzyme production. 2—Optimum enzymatic activity was observed at 55 °C/pH 5. 3—Presence of Ca increased enzyme activity, while EDTA presence had opposite effect.	[45]
Rice straw	Temp., air circulation, moisture, and nutrients should all be appropriately managed. Initial optimal composting ratio of C/N was 25–30.	Psychrophilic and mesophilic micro-organisms.	AnC	Combination of swine manure and rice straw as fertilizer.	1—Organic compound biodegradation caused temperature increase to 40–50 °C. 2—pH in all composts were constant and steady.	[46]
Rice straw	Gravimetric approach to assess moisture content. In-house approach was used to evaluate P and K amounts.	Composting in shaded environment on premium Agro products premises. Two therapies: compost piles with EM (C1) and without EM (C2).	Composting	Final compost in matured stage range could be used without limitation.	Compost treated with EM produces more N, P, and K (*P 0.05*) than compost without EM treatment.	[47]

Waste	Physicochemical Characteristics	Method	Quality Control	Final Products and Uses	Outcomes	References
Rice straw	Individually homogenized substrates and inoculum were deposited at 4 °C for further use.	Effect of characteristics on bio gasification was calculated using Box–Behnken experimental design combined with response surface methodology.	AnC	Research contributes to understanding of intertwined symptoms and microbial activity of Alzheimer's disease.	Bio-gasification of SS-AD of composting RS had significant interactive impact on temperature, ISC, and C/N ratio. Highest biogas output achieved at 35.6 °C with 20% ISC and 29.6:1 C/N ratio	[48]

Table 2. Physiographical properties of organic feedstock materials or different wastes.

Properties	Total Organic C (g/kg)	Total N (g/kg)	C/N ratio	pH	Total P (g/kg)	Total K (g/kg)	Reference
Household waste	368	21.7	17	4.9			[49]
Manure	330	22	15	9.4	3.9	23.2	[50]
Wood chips	394	14.3	28	7.4	3.5		[51]
Sawdust	490	1.1	446	5.2	0.1	0.4	[50]
Canola	457	1.9	24	6.3	1.1	-	[52]
Rice	412	8.7	47	6.8	1.1	-	[52]
Soybean	440	23.8	18	6.3	0.9	-	[52]
Pea	436	35.0	12	6.3	4.6	-	[52]
Rice straw	39.20 [1]	0.64 [1]	61.3	7.6	0.21 [1]	1.12 [1]	[47]
Rape straw		6.52	59.8	7.11	0.99	31.64	[53]
Wheat chaff		5.24	73.8	6.93	0.62	19	[53]
Maize chaff		9.41	46.5	7.03	0.93	22.93	[53]
Rice chaff		8.51	49.1	7.82	0.88	25.31	[53]
Wheat straw biochar	-	1.38 [1]	38	7.03	0.45 [1]	1.06[1]	[54]

[1] Values in percentage. Total N = Total concentration of N. Total P = Total concentration of P. Total k = Total concentration of K.

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