



Composting processes for management waste: A comprehensive review

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Abstract

Composting has become the preferred treatment option for organic waste to produce a final stable disinfected product that can be used as an organic additive. From home composting to large household waste recycling plants, composting is one of the few technologies that can be practically implemented at any scale. Compost is an organic fertilizer obtained from the decomposition of organic waste of plant or animal origin. There are various recipes for making compost. The purpose of the review is to summarize information on the composition of the microbial community of compost, the temperature regime for composting traditional agricultural organic waste, and to analyze the possibility of using the composting process for processing fresh and anaerobically stabilized compacted sludge from municipal wastewater, the organic fraction of solid household waste (SHW), with the addition of lignocellulosic waste.

Keywords: Organic waste, compost, the soil, agriculture, fertilizers, sewage sludge

Introduction

Composting is the biological transformation of solid waste organic materials from plants and animals into a fertile matrix with the help of numerous microorganisms, including actinomycetes, bacteria and fungi, in the presence of oxygen. Adding various micro-organisms to solid waste can turn it into compost or into many by-products such as heat, water and CO₂ [12]. Humus is a hard and stable matrix after a microbiological process that can be usefully applied as an organic fertilizer to improve soil fertility and structure. In ancient history, i.e. the pre-Columbian Amazonian Indians or the ancient Egyptians and numerous prehistoric cultures used composting as a primitive soil improvement method. In the previous four decades, composting technology has flourished, and its beneficial effects are confirmed by scientific research. The vulnerability and interrelation of various competing factors regarding the knowledge and technology of matrix composting technology have been established [3-4].

Innovative composting processes have been developed and used by large and medium-sized farmers, but they are costly for small farmers because these methods require high-tech composting equipment. Despite the separate processes/methods, the key points of the composting processes were indistinguishable each time, as were the natural, chemical and physical characteristics. To study and distinguish between composting and composting processes, the adequacy of different starting materials and modifications, as well as their suitable structure, substrate degradability, moisture management, energy, porosity, air space, energy regulation, and stabilization are necessary [5, 6].

Features of composting organic materials using traditional ways

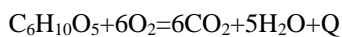
Composts are organic fertilizers formed during the decomposition of organic substances of plant and animal origin under the influence of the vital activity of microorganisms. They are used in agriculture and

landscaping as an organic fertilizer, for reclamation of disturbed lands, restoration of fertility and primary cultivation of reclaimed lands. Compost is the optimal substrate for vermiculture. The agrochemical properties of compost are on par with traditional organic fertilizers such as manure, bird droppings and peat, and in some aspects even surpass them. Fresh manure always contains urea, which, when decomposed, forms ammonia, carbon dioxide and water. Similar transformations with the formation of ammonia as the final product occur with hippuric and uric acids. Therefore, the introduction of fresh manure into the soil can lead to burns of plant roots. Fresh manure is not suitable for fertilizing soils intended for growing root crops. It is noted that when using fresh manure for feeding crops, the growth of vegetative parts of plants is noticeably activated, which does not always mean an increase in yield. On the contrary, in a number of cases, a decrease in yield and resistance to pests and diseases in agricultural crops was noted [7, 8]. Bird droppings is a valuable organic fertilizer, but it cannot be used without pre-treatment. In addition, both manure and bird droppings contain a large amount of weed seeds and pathogenic microflora. Manure and bird droppings are recommended to be composted before use.

Compost is an organic material obtained from various organic materials under the influence of the vital activity of microorganisms. When composting, the processes of fermentation of organic substances occur due to the activity of aerobic microflora. Along with the transformation of organic substances, mineralization to simple compounds and humification occur with the formation of complex organic substances resistant to decomposition. Conventionally, composting proceeds in two stages. The first stage is characterized by the decomposition of organic substances under the action of microflora into simpler organic and mineral compounds. The initial stage of decomposition of organic substances is accompanied by self-heating of the composted material. On days 2-3, the temperature inside the compost heap can reach 60°C. On days 4-5, the temperature

drops slightly. The duration of the stage depends on climatic conditions and the composition of the composted material and takes about 12-14 weeks. Positive temperatures, optimal humidity and good aeration of the substrate activate composting. Aerobic conditions accelerate the process of decomposition of organic substances, which can significantly reduce the time required for this stage to occur. At this stage, raw compost is obtained. Raw compost is not used as a fertilizer, but it is recommended to apply it to the soil to increase the moisture capacity and air permeability of the soil. Raw compost is a source and substrate for soil microorganisms, under the influence of which the second stage of composting can already occur in the soil. The second stage of composting is characterized by the processes of synthesis of organic substances. In this case, the formation of specific humus compounds occurs. The processes occurring at this stage of compost formation are similar to those occurring in the soil, but the intensity of the latter is much lower. The compost obtained after the end of the second stage is called mature. Mature compost contains up to 20% humus, is a homogeneous, crumbly mass, has a characteristic brown color and smell.

For composting, cheap and available materials of plant and animal origin are used. It is advisable to use waste from post-harvest agricultural processing of crops. Tops of vegetable crops, peeling vegetables and fruits, mowed grass, post-harvest residues, fruit cake, spoiled feed are easily subjected to composting. The duration of composting of sunflower and buckwheat husks, straw, sawdust and shavings is much longer, however, the addition of these components to the composting mixture improves the structure of the composted material, helping to improve its friability and hygroscopicity. Fiber contained in plant residues decomposes with the formation of carbon dioxide, water and heat:



The compost mass can warm up to 80°C. An increase in the temperature of the composted mass is provided by the activity of thermophilic bacteria. This temperature is sufficient for the destruction of pathogenic microflora, weed seeds, pathogens of agricultural crops. The biological value of compost as a fertilizer is positively affected by the introduction of organic materials of animal origin. In plant residues there is an excess of carbon and a deficiency of nitrogen. The addition of bird droppings and manure as a source of nitrogen compounds results in high quality compost. The intensity of the composting process depends on the ratio of nitrogen and carbon in the composted materials. The increased carbon content slows down the composting process until the excess carbon is converted to dioxide, and excess nitrogen is released in the form of ammonia and nitrogen oxides, while the loss of ammonia compounds can reach 30%. To minimize the loss of ammonium compounds and intensify the process of decomposition of organic materials, composted materials are treated with microbial preparations.

At present, preparations of "effective microorganisms" are widely known, in particular, "Baikal-EM-1", which has established itself as a highly effective microbiological preparation that increases the yield of horticultural crops [9-13].

Composting sewage sludge

Wastewater treatment technologies at the facilities of communal sewerage systems at the present stage need to be modernized in order to intensify wastewater treatment processes, while reducing their energy intensity. This should be accompanied by the maximum use of the barrier capabilities of existing structures with the addition of existing technological schemes by the construction and equipment of biosludge processing facilities to obtain useful products at the final stage. The analysis of existing wastewater treatment technologies was carried out, on the basis of which the most promising technological process was selected, provided with a set of equipment for processing biosludge. During the composting process, the sludge undergoes physical and chemical transformations with the formation of a stable humified end product, which ensures their disinfection and turns them into valuable components. The resulting organic fertilizers are intended for road maintenance and landscape construction. Composting of sludge allows to drastically reduce its volume and such a technological process is not associated with significant emissions of hazardous substances, therefore it is acceptable from an environmental point of view. Sediments and sludge from municipal wastewater are processed, which are generated into a soil modifier, the so-called. soil suitable for landscape construction and renovation of soil covers. This process is based on cleaning, crushing sludge with the addition of catalysts and intensifying additives, followed by mixing the resulting mass with soil-forming material: peat and mineral additives. The resulting organic fertilizers are intended for road maintenance and landscape construction. Composting of sludge allows to drastically reduce its volume and such a technological process is not associated with significant emissions of hazardous substances, therefore it is acceptable from an environmental point of view. Sediments and sludge from municipal wastewater are processed, which are generated into a soil modifier, the so-called. soil suitable for landscape construction and renovation of soil covers. This process is based on cleaning, crushing sludge with the addition of catalysts and intensifying additives, followed by mixing the resulting mass with soil-forming material: peat and mineral additives. The resulting organic fertilizers are intended for road maintenance and landscape construction. Composting of sludge allows to drastically reduce its volume and such a technological process is not associated with significant emissions of hazardous substances, therefore it is acceptable from an environmental point of view. Sediments and sludge from municipal wastewater are processed, which are generated into a soil modifier, the so-called. soil suitable for landscape construction and renovation of soil covers. This process is based on cleaning, crushing sludge with the addition of catalysts and

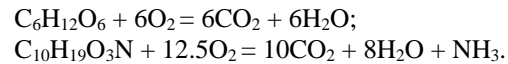
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Composting is the process of biothermal decomposition of the organic matter of the sediment, carried out under the action of microorganisms. Artificial composting takes place under aerobic conditions, which are carried out by saturating the environment with atmospheric oxygen, possibly with the introduction of additives that intensify the process, under conditions of a certain temperature and humidity. In this process, the sediments undergo physical and chemical transformations to form a stable humified end product. This ensures their disinfection and turns the valuable components contained in them into organic fertilizers. The lack of guarantees for the content of harmful and toxic substances implies the use of these fertilizers in a rather limited way: for road maintenance and landscape construction.

Analysis of effluent composting processes

The practice of waste processing shows that the composting of sediments leads to a sharp decrease in their volume. It is especially important that the technological process is not associated with significant emissions of hazardous substances and is therefore acceptable from an environmental point of view.

The aerobic process of decomposition of organic matter is accompanied by the release of 674 kcal of heat and is characterized by the equations:



The duration of the process is significantly affected by the digestibility of organic substances by microorganisms. During the decomposition of easily digestible substances, the main amount of energy is released. The heating of the composted mass and the disinfection of sediments occur due to the incomplete use by microorganisms of the energy they release to maintain their vital activity. During the composting process, the system should lose less heat than produce, which is achieved by increasing the composted mass and isolating it from the environment [14-19].

The process of biothermal decomposition of organic matter of sediments includes three main stages

1. rise in temperature;
2. phase of high temperatures (50-70°C);
3. temperature drop.

The development of mesophilic microorganisms creates favorable conditions for the decomposition of the most heat-loving forms of microbes, assimilating those resistant to decomposition. carbohydrates, which dramatically affects the rate of biochemical reactions. As the temperature rises, favorable conditions are created for the development of thermophilic bacteria, as a result of which a large amount of thermal energy is released. A further increase in temperature leads to inhibition of the growth of thermophilic microorganisms. However, the process does not end. The process of decomposition of organic matter continues during a slow drop in temperature due to the re-development of mesophilic microorganisms and protozoa, which use the cellular substance of dead microorganisms, decomposition products of cellulose and lignin as sources of carbon and nitrogen [20].

The most efficient are the processes of aerobic composting of sewage sludge with recirculation to the beginning of the process of a part of the finished compost and the use of carbon-containing fillers (Figure. 1).

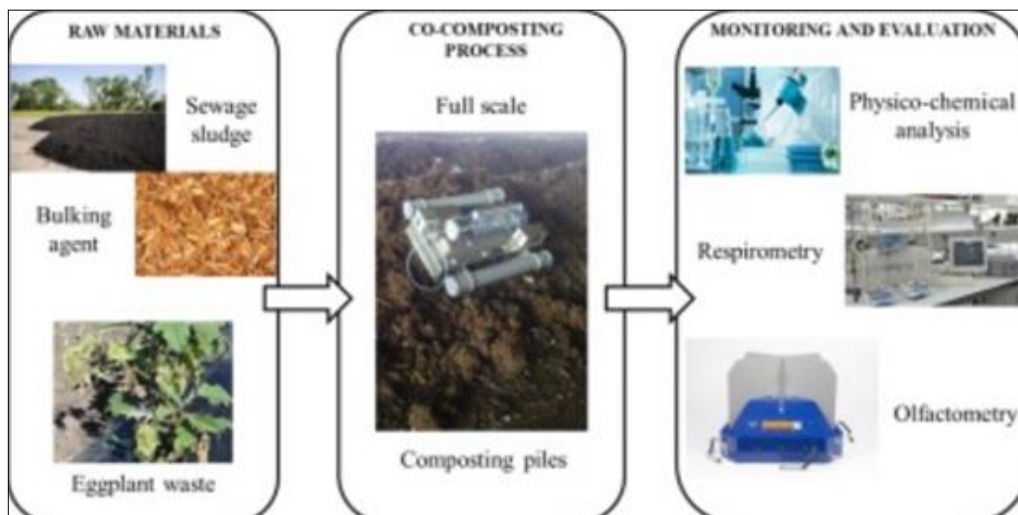


Fig 1: The process of aerobic composting of sewage sludge.

The amount and weight of the added fillers depends on the moisture content and the content of organic matter in the sludge itself and in the filler, and ranges from 1 to 4 volumes of the sludge.

When calculating the components of the mixture supplied for composting, the concentration of dry matter in the initial sediments is of great importance, on which the content of organic matter in the composted mixture depends. If the concentration of dry matter in the sludge decreases, then the amount of recycled compost increases, which reduces the content of organic matter in the recycled mixture. One of the ways to increase the content of organic matter in the composted mass is the use of organic-containing fillers. The most acceptable filler is one that has low moisture content and a high organic content.

Since the content of organic matter in wet sludge is higher than in digested sludge, their composting is economically more profitable. Since during composting the released water is carried out together with the outgoing air, dehydrated sewage sludge with a moisture content of 65-80% is composted together with ground tree bark, shavings, leaves, straw, sawdust, peat, part of the finished compost and other additives that are used as loosening pore-forming, carbon-containing and moisture-absorbing component.

To obtain high-quality compost from sediments, the biothermal process must proceed intensively, without significant loss of organic matter. With accelerated methods of sludge composting, the loss of organic matter should not exceed 20-30%. To do this, it is necessary to carry out the process with efficient mixing of the sludge with fillers, appropriate preparation of the filler, homogenization of the mixture and its saturation with atmospheric oxygen. Ready compost is a loose material with a moisture content of 40-50%, has no smell, does not rot. It contains compounds of nitrogen, phosphorus, potassium. Its use as a fertilizer or soil recultivator is regulated by the content of maximum permissible concentrations of salts of heavy metals. Experiments on composting a raw mixture of sludge from primary clarifiers and compacted activated sludge at sewage treatment plants made it possible to establish that composting materials such as wood waste and lignin should not contain tannins that inhibit the growth of compost flora; the use of fresh waste from the timber industry as fillers can slow down biochemical processes; the maximum permissible content of tannins in wood waste should not exceed 2-4% by weight of dry matter. inhibiting the growth of compost flora; the use of fresh waste from the timber industry as fillers can slow down biochemical processes; the maximum permissible content of tannins in wood waste should not exceed 2-4% by weight of dry matter. inhibiting the growth of compost flora; the use of fresh waste from the timber industry as fillers can slow down biochemical processes; the maximum permissible content of tannins in wood waste should not exceed 2-4% by weight of dry matter.

The complex of equipment for processing the organic part of municipal solid waste is a technological line capable of processing the non-commercial part of municipal solid waste, mainly organic, into soil modifiers - soils. Stages of obtaining a soil modifier:

1. **Composting:** Biothermal decomposition of the organic part of SHW in biodrums to obtain compost;
2. **Screening:** Screening of the non-compostable SHW fraction (ballast screening);
3. **Metal separation:** Selection of small metal inclusions;
4. Crushing the material together with a fermenting additive;
5. Aerobic fermentation of the material;
6. Obtaining the actual soil modifier mixing with additives.

During the treatment of municipal wastewater, the following types of waste are generated ^[7]

- large waste (rags, fibrous and polymeric materials, etc.), retained on gratings and sieves, are called sludge;
- mineral impurities that precipitate in sand traps are called sludge from sand traps;
- **Wet sludge:** Contaminants retained in primary sedimentation tanks;
- excess activated sludge retained in secondary sedimentation tanks;
- compacted activated sludge after sludge thickeners;
- anaerobically digested sludge after digesters;
- **Cake:** sediment dehydrated or dried on sludge beds.

Raw precipitation, retained by primary clarifiers from municipal wastewater are a gelatinous, viscous suspension with a sour smell. Organic matter in it is 75-80%. The mechanical composition of raw sediments is heterogeneous. From 10 mm and more to particles of colloidal and molecular dispersion. Raw precipitation has a moisture content of 94-96%. This significantly complicates their disposal ^[8], affecting the deterioration of the ecological situation and the possibilities of water consumption ^[9].

Excess activated sludge retained by secondary settling tanks is a biocenosis of microorganisms and protozoa, and has the property of flocculation. The structure of activated sludge is a flocculent mass of brown color. When fresh, activated sludge has a supply of earth, but when it rots, it emits a specific putrid odor. According to the mechanical composition, activated sludge refers to fine suspensions, consisting of 98% by weight of particles smaller than 1 mm in size. Activated sludge has a high humidity - 99.2-99.7%

Peat- organic rock, consisting of plant residues that have undergone varying degrees of decomposition. Humus (humus) gives it a dark color. The relative content in the total mass of decay products of plant tissues that have lost their cellular structure is called the degree of decomposition of peat.

Distinguish peat

- Slightly decomposed (up to 20%),
- Moderately decomposed (20-35%)
- Highly decomposed (over 35%).

Peat has a chemical composition

- Carbon 50-60%,
- Hydrogen 5-6.5%,
- Oxygen 30-40%,
- Nitrogen 1-3%,
- Sulfur 0.1-1.5% (sometimes 2.5) per combustible mass.

In the component composition of the organic mass content

- Water-soluble substances 1-5%,
- Bitumen 2-10%,
- Easily hydrolysable compounds 20-40%,
- Pulp 4-10%,
- Humic acids 15-50%,
- Lignin 5-20%.

Peat is characterized by a high moisture content (88-96%), and porosity up to 96-97%. According to the conditions of formation and properties, peat is divided into high, transitional and lowland. High-moor peat, consisting of the remains of sphagnum moss, cotton grass, wild rosemary, is characterized by: low ash content, high calorific value, high moisture capacity (from 600 to 1200%), high acidity, low degree of decomposition.

The use of peat for the preparation of composts based on sewage sludge is a way to improve its characteristics: porosity, density, air capacity, moisture capacity, microbiological and nutritional status. In winter, in the manufacture of composts, the ratio is considered optimal: when mixing - high peat / sewage sludge equal to 2/1; in summer and spring - 1.5/1. Peat optimizes the content of nitrates in grown products, prevents the accumulation of heavy metals and other harmful substances in plants, and reduces the impact of pesticides entering the soil.

Composting processes (VC, AC, AnC)

Numerous studies have examined various composting processes, including vermicomposting (VC), aerobic composting (AC), and anaerobic composting (AnC), to convert agricultural waste into agricultural manure [21-24]. AC - splitting of OM by oxygen-dependent bacteria. Composting bacteria occur naturally and thrive in the moisture that surrounds organic matter. Air oxygen diffuses into a humid environment and is absorbed by bacteria [24]. Mehta and Sirari (2018) stated that AC is the most efficient type of decomposition, producing compost that matures quickly. The biodegradation and stability of OM under conditions favorable for the reproduction and activity of thermophilic microbes leads to the production of a solid, pathogen-free product, ideal for forestry and agriculture. AnC is an "oxygen-free" method in which biodegradable materials are stacked on top of each other in a closed environment. As a rule, digesters are used. Anaerobic microorganisms dominate the AnC process. These microbes produce intermediate chemicals, including hydrogen sulfide, methane and acids, while leaving pathogens and weed seeds intact. VC is the process of using earthworms to compost biodegradable organic materials. Basically, eating all types of OM, earthworms can decompose OM. Earthworms can consume their body weight daily, such as earthworms. Anaerobic microorganisms dominate the AnC process. These microbes produce intermediate chemicals, including hydrogen sulfide, methane and acids, while leaving pathogens and weed seeds intact. VC is the process of using earthworms to compost biodegradable organic materials. Basically, eating all types of OM, earthworms can decompose OM. Earthworms can consume their body

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- a. To highlight the most salient features of the composting method in terms of its stages and their prevalence in various wastes;
- b. Help farmers, researchers and scientists in selecting substrate treatment methods for various crops and assisting them in choosing a composting method by comparing different methods;
- c. Provide a comparison of nutrient-based composting methods; and
- d. Compare two-stage composting (AnC followed by AC) with AC.

Discrete waste composting

Unlike landfilling, which increases the risk of groundwater contamination, discrete waste composting methods are environmentally friendly and avoid groundwater contamination because chemical contaminants and bacteria are reduced during composting. Composting allows persistent organic pollutants and endocrine disruptors to remain in the soil while beneficial bacteria break down toxins. Eliminating these harmful chemicals has not been easy. Although numerous attempts have been made to eradicate them, there has been no universally accepted measure of success. Careful application can increase the sustainability of agriculture and the environment. It also improves soil organic matter and increases agricultural productivity [27] due to the presence of organisms growth-promoting plants and sufficient nutrients in composted residues and contributes significantly to food safety

certification. Compost is useful for bioremediation, weed control [28], plant disease control [29, 30], and erosion control, in addition to its use as a fertilizer. Composting also increases soil biodiversity and reduces environmental risks associated with synthetic fertilizers [29]. Composting is a fundamental aspect of AW comprehensive strategy. A key strategy for practical integrated AW is to improve nutritional levels. Compost is rich in essential plant nutrients such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), carbon (C) and magnesium (Mg), as well as various

important micronutrients [30]. Therefore, compost can be characterized as a set of nutrient-rich organic fertilizers. Compost processing parameters and organic raw materials determine its key chemical properties, such as C/N ratio and pH, (table 1) [31-33]. Total levels of N, P and K can contribute to soil fertility when used as soil improvers. With the right combination of these organic components, nutrient-rich compost substrates can be produced and used in agriculture instead of commercial mineral fertilizers. This aspect is discussed in the following subsections.

Table 1: 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)
Household waste	368	21.7	17	4.9		
Manure	330	22	15	9.4	3.9	23.2
Wood chips	394	14.3	28	7.4	3.5	
Sawdust	490	1.1	446	5.2	0.1	0.4
Canola	457	1.9	24	6.3	1.1	-
Rice	412	8.7	47	6.8	1.1	-
Soybean	440	23.8	18	6.3	0.9	-
Pea	436	35.0	12	6.3	4.6	-
Rice straw	39.20 ¹	0.64 ¹	61.3	7.6	0.21 ¹	1.12 ¹
Rape straw		6.52	59.8	7.11	0.99	31.64
Wheat chaff		5.24	73.8	6.93	0.62	19
Maize chaff		9.41	46.5	7.03	0.93	22.93
Rice chaff		8.51	49.1	7.82	0.88	25.31
Wheat straw biochar	-	1.38 ¹	38	7.03	0.45 ¹	1.06 ¹

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

Biomedical waste (BMW)

Waste generated from the diagnosis, immunization and treatment of humans, research practices and animals are organic BMW. In Pakistan, hospitals produce approximately 2.07 kg of BMW per bed per day [34]. If a BMW is not driven properly, it can cause serious environmental and health problems [34]. Therefore, safe disposal methods need to be explored, and composting is a sustainable option. Neem and Tobacco extracts are cost effective for local small farmers and provide the best organic BMW degradation. Thus, these extracts can be used to turn an organic BMW into a potential fertilizer. Previous studies have shown that BMW need to be similarly treated with 5% sodium hypochlorite (NaOCl) at the disposal site. It can be subjected to an initial decomposition process by mixing with cow slurry and then using VC to process it further. Several types of epigeal worms can be used for this purpose. By using this approach to handling BMW, these worms are more efficient at decomposing and properly handling BMW can be an energy efficient and sustainable method of eliminating and recycling this hazardous waste. At the same time, the processes of composting various wastes proceed in discrete modes. The most commonly used methods are conventional composting, i.e AC, AnC and VC, as well as new composting, e.g. two-stage composting. Several types of epigeal worms can be used for this purpose. By using this approach to handling BMW, these worms are more efficient at decomposing and properly handling BMW can be an energy efficient and sustainable method of eliminating and recycling this hazardous waste. At the same time, the processes of composting various wastes proceed in discrete

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Aerobic composting (AC)

AC is the decomposition of organic matter by microorganisms using oxygen and occurs in the open atmosphere as a pile or pit. For example, green and brown materials are shredded to a size of 2-3 cm or less by the shredder to help them decompose quickly. The shredded material is then placed in a heap/roll with a certain moisture content. Frequent tumbling is used when there is sufficient moisture to mix properly and provide aeration to ensure the survival of the micro-organisms. Microorganisms multiply in organic material with sufficient water and air, and decompose the organic material. After seven to eight turns, the material becomes fine and changes color to dark brown (depending on the material used for composting) with a decrease in odor. The compost is now ready to be used as organic fertilizer. A schematic block diagram of this process is shown in Figure 2.

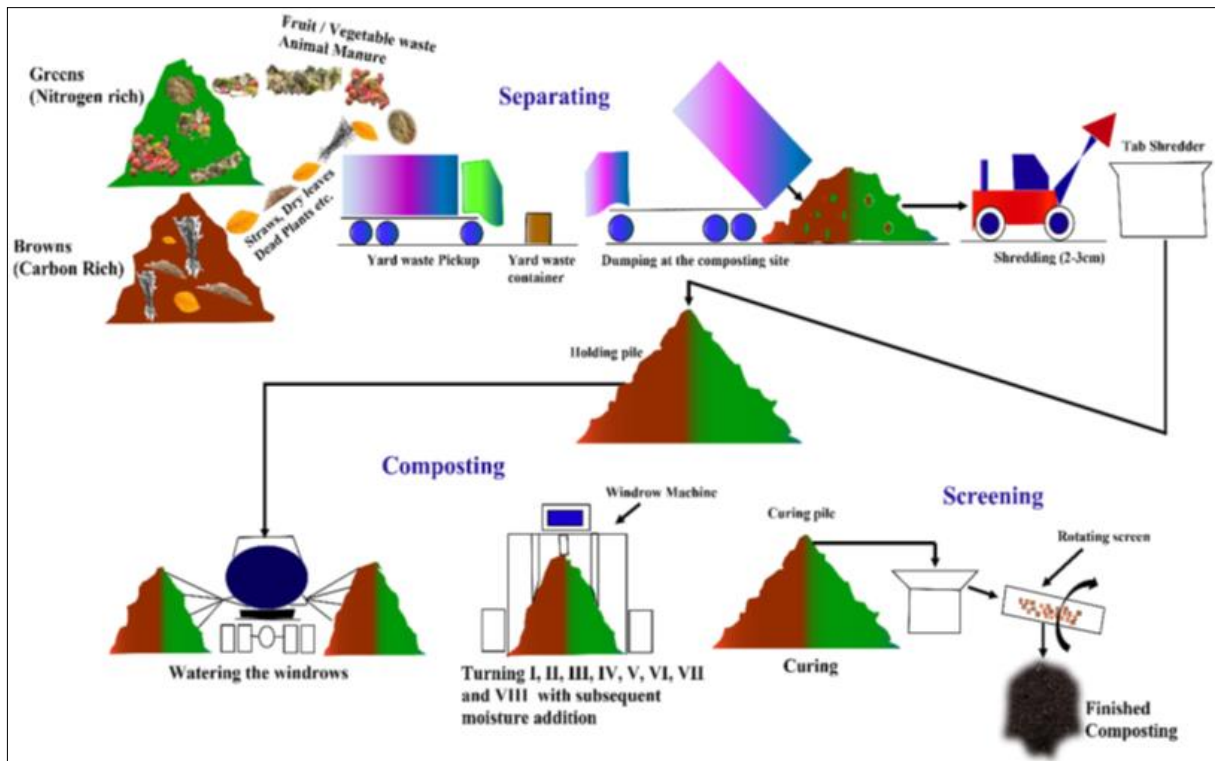


Fig 2: Schematic process flow diagram

Anaerobic composting (AnC)

AnC decomposes organic matter in the presence of microorganisms without the use of oxygen [35]. AnC occurs in two stages. For example, cow dung was fed daily into the biogas digester used in the first stage. The by-product of the digester was a slurry called digester from which all greenhouse gases had been removed. The product has been effectively used for composting and reducing environmental pollution. The slurry was mixed with crushed brown residues of moisture sufficient to carry out further decomposition. The period of AnC is comparatively longer than AC and the schematic diagram is shown in Figure 3.

In the past, AnC has been used to decompose kitchen waste, fly ash and plant residues [35], garden and animal waste [35], household waste [36], sawdust and pig manure [37], and sewage sludge [38]. When AnC was used for the aforementioned feedstock, it reduced greenhouse gas emissions as it occurs in an anoxic environment [39-41] and are considered harmful gases contributing to global warming, eutrophication and acidification if large amounts enter the atmosphere [42]. Methane from anaerobic digestion can be used as an energy source for either electricity generation or combustion.

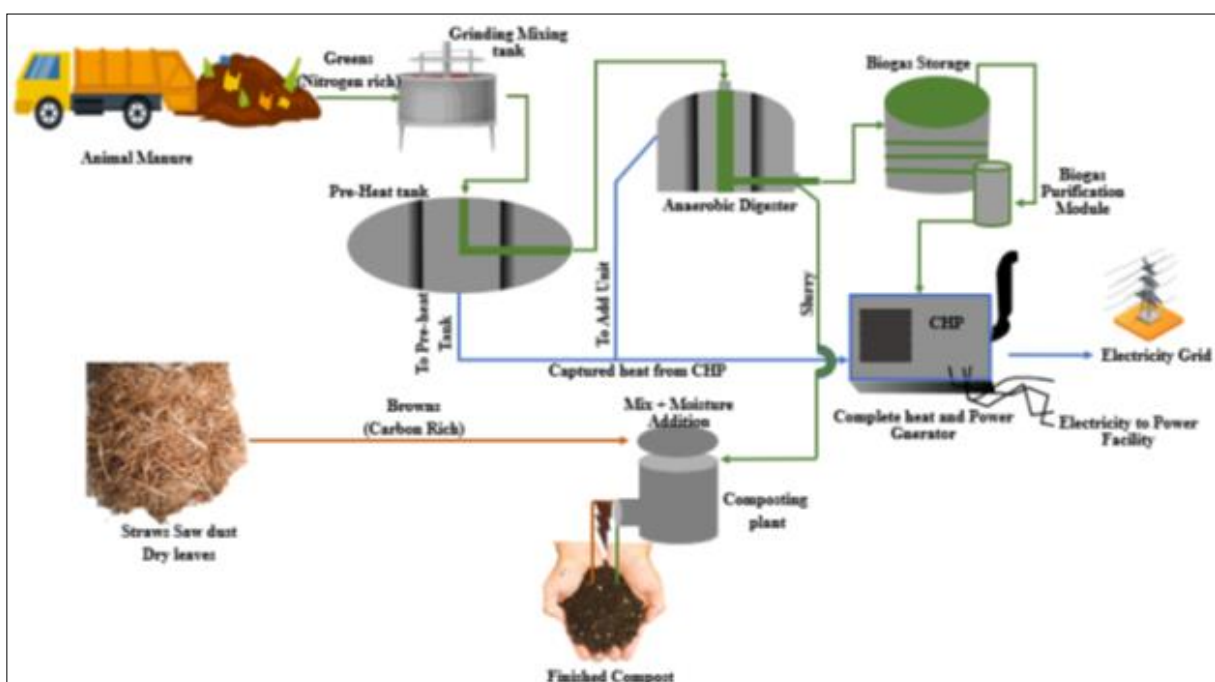


Fig 3: AC circuit diagram

Anaerobic digestion prevents environmental pollution because the methane produced is used and thus removed by incineration. AnC requires large amounts of moisture and nitrogen enriched materials (animal manure, food waste and sewage sludge) to successfully complete and produce useful products for end users. Due to the high humidity at the end of the AnC, compost tea is produced, which can be used as liquid fertilizer enriched with nutrients (N, P and K). In addition, the release of volatile compounds (terpenes, ethers and esters) during periods of active composting in AnC is negligible ^[41]. The preparation of the final product from anaerobic compost requires a longer time. The disadvantage is that the final product of anaerobic fermentation contains intestinal sticks and salmonella that are dangerous to human health. Another negative effect of anaerobic composting is the formation of odors.

Biotechnological processing methods

The task of rational use of wood waste is relevant for most countries with a developed wood processing industry. In the process of obtaining wood at processing enterprises, large-tonnage waste accumulates, among which the bark accounts for an average of up to 10% of the total volume. The main practice of bark waste disposal is dumping or incineration, which creates a negative technogenic burden on the environment. At the same time, the potential of the bark of various tree species as a unique, practically inexhaustible raw material for obtaining various chemicals, sorbents and other materials in demand is well known. Bark waste is an important source of humus formation. The bark contains a variety of organic substances, including easily decomposable and mineral compounds, important for plant nutrition. This makes it possible to return to the cycle of nature the organic part withdrawn from it, which is necessary for the normal functioning of the soil-biotic complex ^[43]. Therefore, it is most rational to use bark waste for the production of organic and organomineral fertilizers. This direction is particularly promising due to the fact that intensive farming leads to a rapid decrease in soil fertility, which is caused by the mineralization of humus. Despite the vast experience gained, obtaining organic and organomineral fertilizers based on tree bark remains an urgent task. Therefore, it is most rational to use bark waste for the production of organic and organomineral fertilizers. This direction is particularly promising due to the fact that intensive farming leads to a rapid decrease in soil fertility, which is caused by the mineralization of humus. Despite the vast experience gained, obtaining organic and organomineral fertilizers based on tree bark remains an urgent task. Therefore, it is most rational to use bark waste for the production of organic and organomineral fertilizers. This direction is particularly promising due to the fact that intensive farming leads to a rapid decrease in soil fertility, which is caused by the mineralization of humus. Despite the vast experience gained, obtaining organic and organomineral fertilizers based on tree bark remains an urgent task.

Biotechnological methods for converting waste wood bark into organomineral fertilizers include: composting, vermicomposting, biodegradation under the action of enzymes and bacteria, bioconversion of the organic matter of the bark under the action of fungi. Composting is the simplest and least expensive way to dispose of wood bark. Interest in obtaining such composts is due to the diversity,

availability and low cost of raw materials. In addition, the introduction of composts has a positive effect on the physicochemical properties of the soil due to the deconsolidation of its upper layer and an increase in the total porosity. This leads to a significant improvement in soil aeration, an increase in its moisture content and water capacity. The introduction of composts is accompanied by an increase in the share of valuable aggregates and their water resistance in the soil, an increase in the content of humus and its mobile forms. It is important to note, that composts favor the biological activity of the soil, which affects its fertility. Composting has a strong effect on the state of the main macronutrients of plants, which can be absorbed on soil particles or form complexes with organic substances. As a result, the nature of their accumulation, water resistance and bioavailability change. When studying the properties of pine bark compost, its inhibitory effect on phytophthora was established.

In terms of the effectiveness of this action, compost is comparable to chemical and biological fungicides, which makes it possible to reduce the share of expensive drugs when growing plants. The main attention in the development of methods for obtaining and improving the composition of composts from tree bark was given to the use of various mineral and organic additives. Additives of traditional fertilizers, vermiculite and natural aluminosilicates are still relevant. Mineral fertilizers allow you to balance the macronutrients in the compost. The introduction of vermiculite and aluminosilicates leads to an increase in the porosity and moisture capacity of the compost, which accelerates the process of biodegradation of the bark. The use of aluminosilicates, due to their specific structure and sorption activity, gives the compost the effect of prolonged action.

The inclusion of additives of hydrophilic polymers and their compounds with metals in the composition of the mixture for composting improves the water balance and aeration of the compost during its bioconversion. Due to these additives, the resulting compost is characterized by high moisture capacity and good water-retaining capacity. Sewage sludge (SS) of various nature is a valuable source of phosphorus, zinc, magnesium and other biogenic elements. The introduction of composts into the soil, in which the content of Mg, Mn, Zn, Co, etc. does not exceed the level of their MPS (maximum permissible concentration, is able to provide a deficit-free balance of macro- and microelements in the crop rotation for a long time. Sewage sludge, along with nutrients, may contain toxic components, such as phenolic compounds. In ^[43], an effective way to reduce the phytotoxicity of SS from olive oil production was demonstrated by composting in the presence of Sesame bark. Kinetic studies have shown that the amount of water-soluble phenol is reduced by 72% within 7 months of composting. After 7 months, no soluble phenolic compounds are found in the compost. At the same time, the achieved C/N ratio and the content of humic substances make it possible to consider compost acceptable for agricultural use.

Joint bioprocessing of waste from brewing, leather and meat production with vegetable waste, including wood bark, makes it possible to obtain organic fertilizers with a wide range of biogenic nutrients (amino acids, microelements) characterized by high availability and digestibility. A review of the literature found that in the last 10–12 years of work

devoted to vermicomposting of tree bark and its bioconversion with the help of fungi. Insignificant attention to these methods of processing wood waste is obviously due to the need to select species of worms and fungi that have optimal productivity for the conversion of the raw materials used. In addition, to obtain high-quality fertilizers, certain conditions and a nutrient medium are required. It should be noted that these methods also have their advantages. For example, vermicomposts are more efficient than regular composts because they contain nutrients in more accessible forms for plants. The positive effect of vermicomposts on plant growth may be associated with the ability of worms to produce certain bioactive metabolites and vitamins of different groups.

Bioconversion of birch bark bast in the presence of fungi of the genus *Trichoderma* under conditions of various nitrogen nutrition (ammonium or nitrate, 3% of the mass of the substrate)

allows you to get a biological product such as "Trichodermin", which is used in the fight against plant diseases, and humus fertilizer. The biological product was obtained in the process of cultivation of fungi under conditions of ammonium nutrition. At the same time, the yield of fungal spores increases 42 times already after 5 days of the process. Bast biodegradation in the presence of nitrate nitrogen is accompanied by its rapid humification – the mass fraction of humic substances reaches 17.9% already on the 4th day of cultivation. This makes it possible to consider this approach to the processing of birch bark waste as more promising than composting. The resulting humus fertilizer is enriched with spores of fungi that can suppress the development of phytopathogens. The main disadvantage of biotechnological methods for processing bark waste into fertilizers is a significant duration. On the dynamics of biodegradation processes, which is especially typical for composting, the bark species has a strong influence. The authors of the works have shown that fertilizer compositions with aspen bark decompose faster than those based on coniferous bark. As a result, it becomes necessary to sort the waste wood bark before laying compost heaps.

Compost stability and maturity

Among the various characteristics that determine the quality of compost, especially for agricultural purposes, are "stability" and "maturity". At different stages of composting, the degree of decomposition and humification of organic matter greatly affects the quality of the final product of the process. As documented, mature composts increase soil organic matter (SOM) content much better than fresh and immature composts due to higher levels of stable carbon (C). However, incomplete decomposition and humification of organic matter will cause the accumulation of harmful substances in the soil and have a toxic effect on plants. In this regard, and in order to avoid such side effects, it is recommended to determine the quality of the compost by determining its degree of maturity and stability. Maturity is used to determine the suitability of the compost for agricultural purposes, considering its effect on plant growth and phytotoxicity aspects, while stability refers to the resistance of organic matter to extensive biodegradation or microbiological activity. It is important to note, that when determining the quality of compost, both characteristics (i.e. maturity and stability) should be considered and compared

together, since phytotoxic compounds are products of microbial activity of unstable organic matter. Various tests have been used in the literature to assess the stability and maturity of compost. In this context, respiration methods based on oxygen consumption by microbial activity are considered the most useful methods to determine compost stability and maturity, but germination tests are also widely used to determine compost maturity. The respiration index for the decomposition of various materials correlates with the content of organic matter and the biochemical reactions of microbial activity. For example, materials with a respiratory index of 0.5 to 1.5 mg of O₂ g⁻¹OM h⁻¹ are considered stable, and values above 1.5 mg O₂ g⁻¹OM h⁻¹ correspond to unstable materials.

The ideal form of nutrients in compost

The application of compost on normal and saline soils is an important practice to improve soil organic matter and mineralization, especially in arid and semi-arid regions^[44], which constitutes the bulk of the cultivated area worldwide, mainly due to low rainfall and increased alkalinity. Indeed, soil organic matter is essential for maintaining soil fertility and reducing nutrient losses. In addition, it is responsible for many soil characteristics, including water holding capacity, soil productivity, biological activity environment, soil aeration, and soil structure^[44]. It is well known that nitrogen is the most essential fertilizer affecting plant ontogeny. In ordinary soil under conditions, 95% of nitrogen and sulfur are available in organic matter, although 25% phosphorus is also available. Because compost is made up of decomposed organic waste, it naturally contains a good percentage of nitrogen. Therefore, adding compost to the soil enriches it with important elements for plant growth and development, such as nitrogen, carbon, sulfur and phosphorus. The conditions of the composting process and the type of organic raw materials are the main factors affecting the availability of nutrients and the stability of the humus-like form of the product. Indeed, N and C are the most important elements to be calibrated for the maturation period of the pile. The C/N ratio should be between 25 and 30, and the average biocompost should contain about 33.3% organic matter, but not less than 20%. The compost should also contain no more than 40% water, and about 35% water is recommended for commercial compost. The ideal compost pH for most agricultural applications should be around 7.5. In addition, an important parameter is the salt content; it should be about 3.89 g per liter of fresh substance. Phosphate is available as P₂O₅ in the compost at about 0.62% DM (dry matter), while the potassium content is about 1.01%.

Potential risks of using compost in agriculture

As shown in several studies, compost can improve soil properties and soil fertility, which, as a result, increases crop yields. However, to ensure safe and optimal composting, knowledge of the best application rates and timing is required to reduce or even avoid negative impacts on soil and the environment. The quality of the compost must meet certain characteristics, including but not limited to organic matter content, heavy metal content, nutrient content, pathogen content, maturity and stability. Below are the potential risks associated with the use of compost in agriculture:

- Increasing soil salinity: High salinity of compost applied to the soil has been reported to delay plant germination.
- The possibility of accumulation of heavy metals in soils and plants can occur when the concentrations of heavy metals exceed the permissible limits, and compost is applied in large quantities. However, it is important to note that soil type, compost type, and irrigation system are important factors influencing this type of pollution.
- Nutrient leaching: When a large amount of compost is spread over a relatively small area, it increases the chance of nutrient leaching, especially in autumn and winter. High concentrations of nitrates can leach from soils and contaminate surface and groundwater.
- In addition, nitrate leaching in the presence of other nutrients such as phosphorus can contribute to water eutrophication.
- Composts derived from sewage sludge can contribute to the release of ammonia, mainly when they have high concentrations of ammonium. In addition, these types of compost are characterized by a high potential for contamination by pathogenic microorganisms.
- Degradation of soil aggregates as a result of the breakdown of soil colloids in the case of high concentrations of cations such as Na^+ and K^+ . [In addition, other pollutants such as persistent organic pollutants and potentially toxic elements can come from some types of composts.

It is worth noting that these risks can be minimized by taking into account the application rate of the compost, the type of soil, the time of application, and the stability and maturity of the compost. In addition, the migration and transformation of contaminants can be studied before composting. However, more research is needed to give a clear picture of these issues. In any case, research has powerful tools, such as life cycle assessment, to determine the advantages/disadvantages of cradle-to-grave composting. However, it is important to emphasize that, although a significant number of studies have assessed the composting technology in terms of emissions or overall impact, it is still relatively difficult to find studies in which all aspects of compost applications are addressed using reliable and experimental data ^[45-48].

Conclusion

This review shows the positive results of the use of compost in agriculture. The general conclusion is simple, if the composting process is carried out correctly and the compost is stable and seasoned, then the compost is a reserve of macro- and microelements that can replace chemical fertilizers. Compost also has other effects such as suppression of plant diseases. Overall, the results presented in this review indicate that the application of compost is environmentally appropriate, with a wide range of uses and purposes, such as the bioremediation of several hazardous pollutants. Several new compost formulations such as compost tea, vermicompost, or customized compost with various biopesticides are new areas of research that need to be considered in the future.

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