Chapter

Composting

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Abstract

Decomposition followed by stabilization of organic substances by biological actions has been taking place in nature from the very beginning of life appeared on our planet. Anthropogenic control and utilization of the process for sanitary disposal and reclamation of organic waste material have been termed composting and the final product is named compost. Microbial community leads the processes of both aerobic and anaerobic composting and converts wastes to a stable form of nutrients. The C/N ratio is the most important factor for decomposition, especially aerobic decomposition. Microorganisms respire two-third of carbon as CO_2, and one-third combines with nitrogen in living cell, and huge amount of heat energy is released as end product of aerobic decomposition as compared to anaerobic process. In agricultural world, utilization of human and animal wastes has great importance. Extensive studies on composting were initiated in India. Different composting methods like pit method, heap method, ADCO method, vermicomposting, etc. presently exist in the world. Humus is the end product of composting, and different organic wastes contain macro, micro, and trace elements, which reflect valuable properties for growing vegetation and to the soil itself.

Keywords: composting, anthropogenic, microorganism, vermicomposting, humus, elements

1. Introduction

Composting is a very old art, and some of its basic principles have been appreciated and used in practice for centuries. In recent years, however, rapid progress has been made in scientific studies of the underlying biological and chemical processes involved in composting. These studies have served to clarify several factors which can act to produce finished compost which is both valuable to agriculture and relatively safe from the viewpoint of public health [1].

There is an important relationship between sanitation and agriculture in all parts of the world. In agricultural areas, the utilization of human and animal wastes is of great importance from both the public health and the agricultural points of view. This is because of (a) the ever-increasing difficulties in disposing of great accumulations of wastes, (b) the ever-increasing threat to soil fertility, and (c) the intensive ever-increasing waste demand for agricultural lands to produce more food.

Sir Albert Howard and his associates [1] first suggested modern composting through his book *An Agricultural Testament* (1940) [2]. They studied in India, which was which was carried forward by Acharya and Subrahmanyan [3], further has been investigated extensively by Scott [4] and van Vuren by Gotaas [5] and his associates—McGauhey, Golueke, and Card—at the University of California [6], and by many others in different parts of the world.

2. Decomposition

Decomposition or stabilization of organic matter by biological action is the most valuable portion of life cycle on our planet. In recent times, man has attempted to control and directly utilize the process for sanitary disposal and reclamation of organic waste material, and this process has been termed "composting," and the final product of composting has been called "compost" [1].

Generally speaking there are two processes: (a) aerobic decomposition and stabilization and (b) anaerobic fermentation. In these processes, microbial community feed upon organic materials such as vegetable matter, animal manure, night soil, and other organic refuse and convert the wastes to a more stable form.

2.1 Aerobic decomposition

When organic material is decomposed in the presence of oxygen, the process is called aerobic. In aerobic stabilization, living organisms, which utilize oxygen, feed upon the organic matter and develop cell protoplasm from the nitrogen. From the nitrogen, phosphorus carbon and other required nutrients. Much of the carbon serves as a source of energy for the organisms and is burned up and respired as carbon dioxide. Since carbon serves both as a source of energy and as an element in the cell protoplasm, much more carbon than nitrogen is needed. Generally about two-thirds of the carbon is required as carbon dioxide (CO_2), while the other third is combined with nitrogen in the living cells. If the excess of carbon over nitrogen in organic materials being decomposed is too great, biological activity diminishes, and several cycles of organisms may be required to burn up most of the carbon. When some of the organisms die, their stored nitrogen and carbon become available to other organisms. The utilization of nitrogen from the dead cells by other organisms to form new cell material requires the burning of excess carbon to CO_2. Thus, the amount of carbon is required, and the limited amount of nitrogen is recycled. Finally, when the ratio of available carbon to available nitrogen is sufficiently low, nitrogen is released as ammonia. Under favorable conditions, some ammonia may be oxidized to nitrate. Phosphorus, potash, and various micronutrients are also essential for biological growth. These are normally present in more than adequate amounts in compostable materials and present no problem; hence, a discussion of their metabolism by the biological cells will not be included [1]. The cycle of nitrogen and carbon in aerobic decomposition is structured in **Figure 1**.

2.2 Anaerobic decomposition

Putrefactive breakdown of organic material takes place anaerobically. Anaerobic living organisms in metabolizing nutrients break down the organic compounds by a process of reduction. As in aerobic process, the organisms use nitrogen, phosphorus, and other nutrients in developing cell protoplasm but reduce organic nitrogen to organic acids and ammonia. Carbon from organic compounds which is not utilized in the cell protein is liberated mainly in the reduced form of methane (CH_4). A small portion of carbon may be respired as CO_2 [1].

This process takes place in nature as in the decomposition of organic muds at the bottom of marshes and in buried organic material to which oxygen does not have access. The marsh gas which rises is largely CH_4. Intensive reduction of organic matter by putrefaction is usually accompanied by disagreeable odors of hydrogen sulfide and of reduced organic compounds which contain sulfur, such as mercaptans [1].

Since anaerobic destruction of organic matter is a reduction process, the final product, humus, is a subject to some aerobic oxidation when put on the soil. This

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oxidation is minor, takes place rapidly, and is of no consequences in the utilization of the material on the soil [1]. The cycle of nitrogen and carbon in anaerobic decomposition is structured in **Figure 2**.

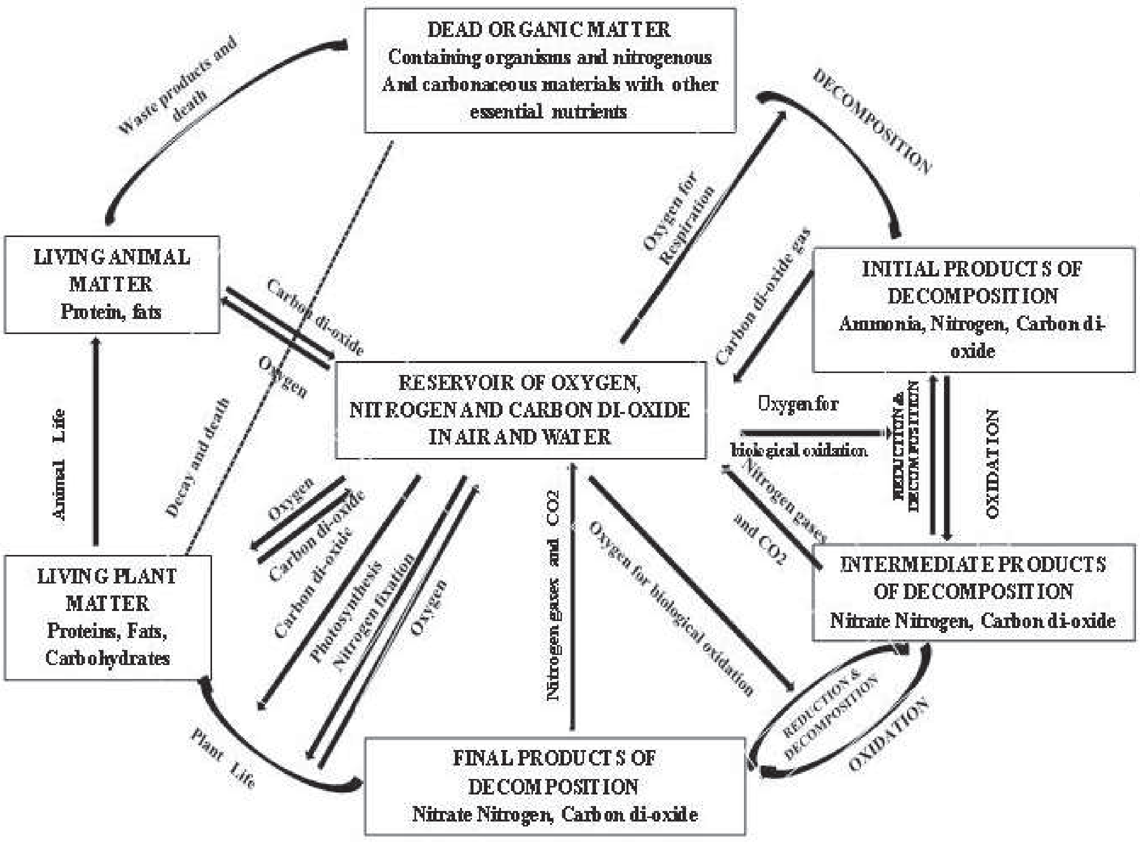

Figure 1.
Cycle of nitrogen and carbon in aerobic decomposition [7].

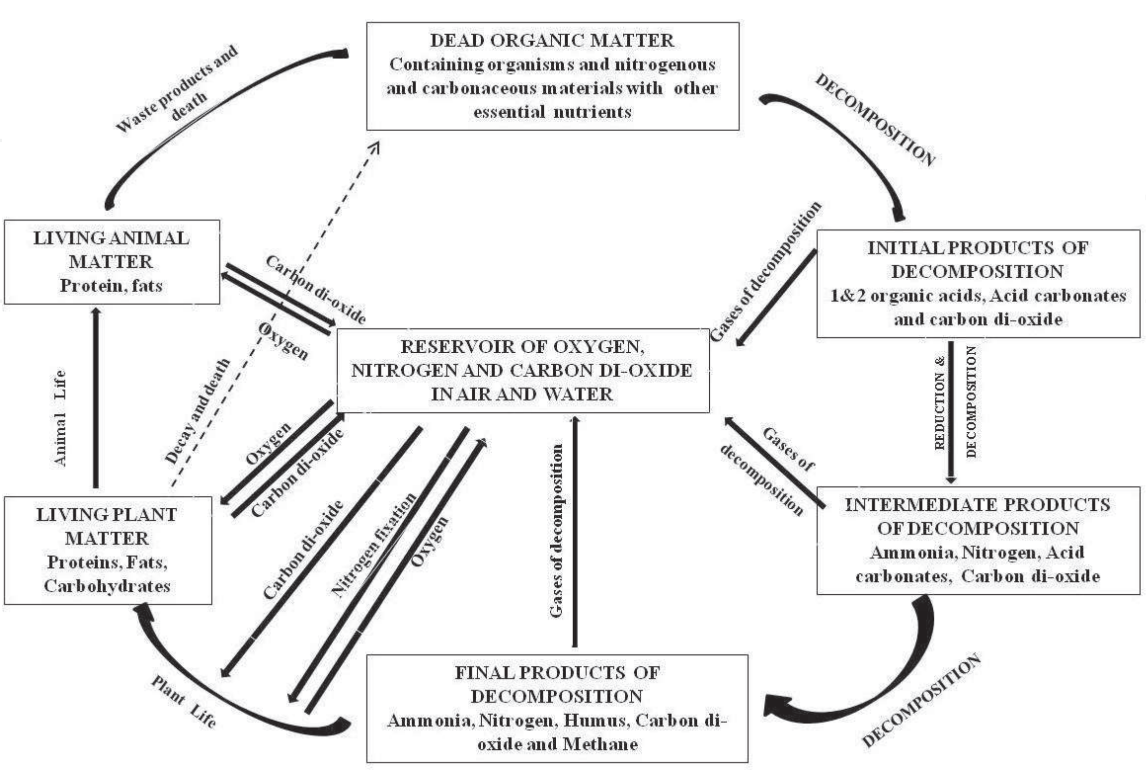

Figure 2.
Cycle of nitrogen and carbon in anaerobic decomposition [7].

3. Raw material

The quantity, characteristics, and composition of wastes available for composting vary widely with season and different localities. The multiplicity and complexity of the factors affecting the quality and quantity of compostable refuse prohibit the use of any formula or rule-of-thumb method for determining the amount of waste material to be expected at any given place [1]. Either a study of specific place or the use of information obtained from studies of places with very similar characteristics is necessary for estimating the quality and quantity of refuse for a given population. These are basic information, useful in supplementing local data in analyzing a particular composting operation.

In a particular agricultural village, following basic quantity and quality data will be useful for studying a compost operation.

3.1 Human feces without urine

Approximate quantity: 135–270 g per capita per day moist weight and 35–70 g per capita per day dry weight

Approximate composition: Moisture, 66–80%; organic matter (dry basis), 88–97%; nitrogen, 5.0–7.0%; phosphate (P_2O_5), 3.0–5.4%; potash (K_2O), 1.0–2.5%; carbon, 40–55%; calcium oxide, 4–5%; C/N ratio, 5–10 [8]

3.2 Human urine

Approximate quantity: 1.0–1.3 liters per capita per day and 50–70 g per capita per day

Approximate composition: Moisture, 93–96%; organic matter (dry basis), 65–85%; nitrogen, 15–19%; phosphate (P_2O_5), 2.5–5.0%; potash (K_2O), 3.0–4.5%; carbon, 11–17%; calcium oxide, 4.5–6% [8]

3.3 Animal manure

The quantity of animal manure varies widely with different conditions of feeding and stabling. Van Slyke [9] gave the information shown in **Table 1** on animal excrement production.

The stable manure is approximately composed with three main components: (a) bedding or vegetable matter litter, (b) solid excreta, and (c) urine. The characteristics and relative concentration of these components vary widely, depending on the type of animal, the stable feeding and handling, and the use to which the animal is put. Straw and plant residues used for bedding usually contain large amounts of carbon, particularly in the form of cellulose and small amounts of nitrogen and minerals. Considerable amount of protein is present in the solid excreta and provide balance nutrient material for the growth of microorganisms [1]. **Table 2** [10] reflects the chemical constituents in fresh manure from different animals, and **Table 3** [11] shows the chemical nature of different types of manure.

3.4 Refuse (garbage, rubbish, other litter)

The most available quantities of garbage, organic rubbish, and dead vegetables are used for animal feed. There is also little waste paper, rags, etc. in the refuse. Ash, particularly in cold climate, street sweeping, and trash constitute a major portion of waste. In warm areas with high rainfall, much waste vegetation finds its way into the refuse. However, in many villages the amount of such refuse is sufficient in

Animal	Tonnes per year per 454 kg live weight	Nitrogen (kg per year per 454 kg live weight)		
		Liquid	Solid	Total
Horse	9.00	2.5	3.8	6.3
Cow	13.5	2.2	2.2	4.4
Pig	15.3	1.8	1.6	3.4
Sheep	6.3	4.5	4.9	9.4
Poultry	4.3	—	9.1	9.1

Table 1.
Quantities of animal excrement [9].

Chemical constituents	Sheep manure	Horse manure	Cow manure
Ether-soluble substances	2.8	1.9	2.8
Cold-water-soluble organic matter	19.2	3.2	5.0
Hot-water-soluble organic matter	5.7	2.4	5.3
Hemicelluloses	18.5	23.5	18.6
Cellulose	18.7	27.5	25.2
Lignin	20.7	14.2	20.2
Total protein	25.5	6.8	14.9
Ash	17.2	9.1	13.0

Table 2.
Chemical composition of fresh manure from various animals (on the basis of dry, litter-free material) (in %) [10].

Manure	Moisture (%)	Composition of dry matter		
		Nitrogen (%)	Phosphate (%)	Potash (%)
Cattle	80	1.67	1.11	0.56
Horse	75	2.29	1.25	1.38
Sheep	68	3.75	1.87	1.25
Pig	82	3.75	3.13	2.50
Hen	56	6.27	5.92	3.27
Pigeon	52	5.68	5.74	3.23

Table 3.
Chemical nature of different types of manure [11].

quantity to provide a satisfactory compostable mass when mixed with night soil and animal manure. The approximate quantity of garbage in village is usually 220–340 g per capita per day with the following composition: moisture content, 10–60%; organic content (dry basis), 25–35%; nitrogen, 0.4–0.8%; phosphate, 0.2–0.5%; potash, 0.8–1.5%; carbon, 12–17%; and calcium oxide, 4.0–7.5% [1].

3.5 Slaughterhouse wastes

The amount of these wastes is extremely variable, depending upon the extent of processing. In small house with no by-product processing, the compostable wastes will be as much as 22–36 kg (dry basis) per ton of meat processed, while in large plant with by-product processing, the compostable wastes will be 11–18 kg (dry basis) per ton. The composition of slaughterhouse waste varies with the extent of utilization of wastes for the manufacture of by-products. Most rural slaughter-houses have primitive recovery processes, and the wastes consist of blood, unsalable meat, intestines, offal, paunch manure, hoofs, etc. and have the following average composition: moisture content, 75–80%; organic matter (dry basis), 80–95%; nitrogen, 8–11%; phosphate, 3.0–3.5%; potash, 2.0–2.5%; carbon, 14–17%, and calcium oxide, 3.0–3.5% [1].

4. Cities and urban centers

Compostable urban wastes probably vary as to quantity and composition almost as much as do rural wastes. Some basic data pertaining to cities with water-carried sewage collection and regularly operated garbage and refuse collection systems that can supplement local information in analyzing municipal composting operations will be shown. Sewage sludge, either fresh or digested, can be composted with garbage and other refuse with sufficient moisture so that the mass will compost aerobically. The quantities and composition of sewage solids and of the sludge are shown in **Table 4**.

In industrial areas, the waste composition and quantity vary with the type of industry. Domestic and food establishment waste garbage quantity depends on climate, food-preservation facilities, type of food used, and utilization of garbage for stock food and the economic status of the community. Domestic wastes vary from 90 to 400 g per day per capita with 60–85% moisture and 65–85% organic matter on dry weight basis. On the other hand, quantities of nonconsumable and non-compostable rubbish such as cans, bottles, china, and metal vary from 45 to 500 g per capita per day [5].

5. Different methods of composting

5.1 Indore method

During the early days of organic gardening/farming, this method was the only systematic way to mature compost. This method developed at the Institute of Plant Industry, Indore, India, between 1924 and 1931, was designed and described by Sir Albert Howard, known as the father of modern organic farming, in his dissertation on organic agriculture *An Agricultural Testament* (1940). In this method, animal dung is used as the catalytic agent along with different types of organic wastes available on the farm.

The steps followed for preparation of compost by Indore method are given below:

i. A compost heap of suitable size say 3 m × 1.5 m × 1 m (length × width × depth) is prepared. The selected site should be near the cattle shed and water source and at an elevated site so that no rainwater floods into the pit during rainy season.

ii. Organic wastes of different sources available on a farm are accumulated near the trench and mixed thoroughly. Hard woody materials (not exceeding 10% of the total plant residues) are crushed before being piled. Green materials,

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	Quantity of solid (dry basis) g/head/day	Liquid sludge (% solid)	Drying bed cake (% solid)	Vacuum filter cake (% solid)	Composition on dry basis (%)				
					Organic	Mineral	Nitrogen	Phosphate	Potash
1. Fresh domestic sewage	81.6–99.7	0.04–0.15	—	—	60–85	15–40	5.0–10.0	2.5–4.5	3.0–4.5
2. Imhoff tank	22.7–36.3	8.0–12.0	35–50	—	30–45	55–70	2.0–3.0	1.2–3.5	0.1–0.5
3. Primary, fresh	45.4–63.5	2.5–5.0	28–45	22–34	60–80	20–35	1.5–4.0	0.8–4.0	0.1–0.5
4. Primary digested	27.2–40.8	5.0–12.0	35–50	26–34	35–60	40–65	1.0–3.5	1.2–4.0	0.1–0.5
5. Primary and trickling filter, humus fresh	59.0–77.1	3.5–6.5	26–40	23–34	50–75	25–50	2.0–4.5	0.8–3.6	0.1–0.5
6. Primary and trickling filter, humus digested	36.3–50.0	5.0–12.0	35–50	25–35	35–60	40–65	1.0–3.5	1.0–3.8	0.1–0.5
7. Primary and activated sludge, fresh	72.6–90.7	3.0–6.0	26–40	20–24	50–80	20–50	2.3–5.2	1.2–4.0	0.2–0.6
8. Primary and activated sludge, digested	45.4–59.0	45.8.5	28–50	22–26	35–55	45–65	2.0–4.8	1.3–4.0	0.2–0.6
9. Primary sludge, digested, and fresh activated sludge	54.4–72.6	2.5–4.5	28–45	20–24	40–60	40–60	2.2–3.0	1.3–4.0	0.3–0.8

Table 4.
Approximate quantity and composition of sewage and sewage sludge [5].

which are soft and succulent, are allowed to wilt for 2 to 3 days in order to remove excess moisture before stacking; these tend to pack closely when stacked in the fresh state. The mixture of different kinds of organic materials/residues ensures a more efficient decomposition [12].

iii. The compost heap is built in layers. First a layer of refuse/organic wastes like weeds, crop residue, grass clippings, or leaves of about 15–20 cm (6–8 inch) thick is spread at the base of the heap. Next a 5 cm (2 inch) layer of cattle dung slurry and water is added onto the refuse. A third layer of the same size of the first is then spread followed by a layer of slurry of cattle dung and water. This layering sequence is continued till the heap is raised to a height of 50–100 cm above the ground level. The top is then covered with a thin layer of soil, and the heap is kept moist.

iv. The filling of heap is completed within 6–7 days to fill the three-fourth length of the trench, leaving 1/4th length empty to facilitate subsequent turnings.

v. Water is sprayed on regular basis so as to keep the moisture content to about 60–80%.

vi. Turning is done three times, at 15, 30, and 60 days after compost filling in order to allow air to penetrate so that the heap will heat up properly. At each turning the whole mass is mixed thoroughly. This can be done manually or mechanically.

The main advantage of this method is that the finished compost is ready within 4–5 months for application to the soil. The composed prepared by this method contains, on an average, 0.8% N, 0.3–0.5% P_2O_5, and 1.0–1.5% K_2O. Periodic turning of composting mass helps the process to remain aerobic throughout the decomposition and facilitate faster decomposition by bringing the substrates which are undecomposed or partially decomposed with the microorganisms and air. As it requires extra labor, the cost of preparation of compost is more. Heat is generated during the decomposition process inside the compost pit which helps in destroying most of the pathogens and weed seeds. When sufficient nitrogenous material is not available, a green manure or leguminous crop like sunnhemp *(Crotalaria juncea*) may be grown on the fermenting heap after the first turning. The green matter is then turned in at the second mixing [12].

5.2 Bangalore method

This method is an anaerobic process, developed at the Indian Institute of Science, Bangalore, by the late Dr. C.N. Acharyain in 1939. It is recommended where night soil and refuse are used for preparing the compost. This method overcomes many of the disadvantages of the Indore method, such as the problem of heap protection from adverse weather, nutrient losses from intensive rains and strong sun, frequent turning requirements, and fly nuisance [12]. The method is suitable for areas with scanty rainfall. The compost is done in the trenches of 9.1 m × 1.8 m × 0.9 m (=302′ × 62′ × 32′) or in the pits of 6.1 m × 1.8 m × 0.9 m (= 202′ × 62′ × 32′). This method saves on labor cost because there is no need of turning and regular sprinkling of water but takes much longer time to finish [12].

This method includes the following steps:

i. As like Indore method, the mixed farm residues are spread at the bottom of a trench or pit of a convenient size, similar to that of Indore method. Generally, trenches or pits about 1 m deep are dug 1 m in breadth, and the length of the trenches can vary according to the availability of land and the type of material to be composted. The trenches should preferably have sloping walls and floor to prevent water logging.

ii. Organic residues and night soil are put in alternate layers. The trench or pit is filled layer-wise till the raw material reaches about 50 cm above the surface. Here 100% space of pit is used.

iii. The pit is covered with 15–20-cm thick layer of refuse and then plastered with a 2–5 cm layer of a mixture of mud and cattle dung. Plastering of pit prevents the loss of moisture and fly nuisance. This method effectively controls foul smell and kills pathogenic organisms.

iv. The materials are allowed to remain in the pit without turning and watering. During this period the material settles down due to reduction in the volume of biomass. Under such conditions, decomposition is largely anaerobic and high temperatures do not develop. The C/N ratio of the finished product drops to a value below 20:1 with no odor, indicating that the compost is ready to use.

v. The material undergoes anaerobic decomposition at a very slow rate, and it takes about 6–8 months to obtain the finished product.

vi. The recovery of the finished product is greater than aerobic composting.

vii. Labor requirements are less than for the Indore method as turning of material is not done; labor is needed only for digging and filling the pits.

Organic nitrogenous compounds gradually become soluble, and the carbonaceous matter breaks down into CO_2 and H_2O. The loss of ammonia is negligible because in high concentrations of CO_2, forming ammonium carbonate is stable. The anaerobic process is particularly suited for use by gardeners in or near cities and towns. The well-decomposed compost contains 0.8–1.0% N. A uniform high temperature is not assured in the biomass. Problems of odor and fly breeding need to be taken care of. After 8–9 months, all the material decomposes, and the compost becomes ready for application.

5.3 NADEP composting

This method of composting was developed by Sri Narayan Deorao Pandharipande. He was an old Gandhian worker, popularly known as "Nadep Kaka" from Maharashtra. He worked for 25 years at the Dr. Kumarappa Gowardhan Kendra at Pusa to perfect his composting technique [2]. This process facilitates aerobic decomposition of organic matter. This method takes care of all the disadvantages of heaping of farm residues and cattle shed wastes in the open condition. This method envisages a lot of composting through minimum use of cattle dung. It requires composting materials like dung, farm residues, soil, waste products of agriculture, etc. Decomposition process follows the "aerobic" route and requires about 3–4 months for obtaining the finished product.

This method includes the following steps:

i. A brick structure measuring 9′ × 6′ × 3′ with perforated holes in all the side walls is prepared to ensure adequate supply of air during composting. It is carried out in specially constructed tanks with walls built like "honeycombs" through which water is sprayed to prevent the compost from becoming dry. This aboveground-perforated structure facilitates passage of air for aerobic decomposition. The floor of the tank is laid with bricks and covered above with a thatched roof. This prevents loss of nutrients by seepage or evaporation, and the contents are not exposed to sunshine and rain [12].

ii. The brick tank is plastered with cattle dung slurry to facilitate bacterial culture for decomposition of biodegradable wastes. The brick tank is then filled layer-wise first with a thick layer (10–15 cm) of chopped fine stick of semihard wood which helps in providing aeration, followed by a same layer of farm wastes or dry and green biomass or any other biodegradable material to be composted.

iii. Prepared slurry of mixing cattle dung (5–10 kg) with water (100 liters) is then sprinkled thoroughly on the biodegradable mass in order to facilitate bacterial culture for faster decomposition. On it a layer of soil is maintained in order to compress the volume of the wastes. Addition of soil also facilities retention of moisture, provides microorganisms, acts as buffer, and controls pH of the compost during decomposition. The nutrients produced in the manure are absorbed by the soil layers, thus preventing nutrient loss.

iv. The whole tank is thus filled completely with about 10–12 layers in the same sequence having 1–3 sub-layers in each layer. After 2–4 weeks, the volume of the composting mass is reduced to almost two-third of the original. At this stage, additional layers of composting mass are formed over it keeping the same sequential set up, already said. Finally, the whole biomass is plastered and sealed with slurry of cattle dung and mud. In this condition, the tank is allowed to decompose the biodegradable wastes for further 3 months. Water is added on regular basis to maintain the moisture content between 60 and 75% throughout the composting period.

v. It is advisable to sprinkle microbial cultures like *Trichoderma*, *Azotobacter*, and *Rhizobium* and phosphate-solubilizing microorganisms in each layer to enhance the equivalent speed of composting process at each corner of the compost.

vi. Compost becomes ready for use within 110–120 days after composting. So one tank can be used three times annually.

vii. The prepared compost can be stored for future use, preferably in a thatched shed after air-drying and maintaining it at about 20% moisture level by sprinkling water whenever needed. Also storage at gunny bag in shade areas is also preferable. By following this procedure, the composed could be preserved for about 6–8 months.

viii. Requirement of higher labor and inconvenience faced in filling during rainy season are the two difficulties experienced by the farmers in adopting NADEP method of composting.

5.4 Municipal solid waste composting (MSW)

MSW composting or mechanical composting is followed in big cities, where huge quantities of garbage are generated. The metropolitan cities like Mumbai, Kolkata, Delhi, and Chennai generate about 2000–6000 tonnes garbage per day, posing gigantic disposal problems. Mechanical composting plants with capacity of 500–1000 t day-1 of city garbage could be conveniently installed in big cities and 200 t day-1 plants in the small towns in India. The adoption of accelerated fermentation treatment enables 70% of the refuge to be available as refined compost in the form of a dry, black free-following material, easy to transport and handle. Such refined mechanical compost contains generally equivalent amount of mineral matter and organic matter with half of organic carbon. The composition of the compost is variable and at par with the raw materials used. On an average, it may contain 0.7% N, 0.5% P_2O_5, and 0.4% K_2O and a C/N ratio of 15–17. Mechanical composting has several advantages such as (i) environmental sanitation to minimize pollution, (ii) recycling of discarded wastes into a value-added product, and (iii) production of compost within a short period [12].

5.5 Enriched compost

In general, the bulky organic manures like FYM contains around 0.5–1.0% N, 0.2–0.5% P_2O_5, and 0.5–1.0% K_2O. The cost of preparation, storage, transport, and application of FYM or compost to soils is high. The demerits of bulky manures can be overcome through the preparation of enriched compost by adding nitrogen, phosphorus, potassium, and micronutrients either alone or in combination [13].

Enriched composts have the following advantages:

i. Enriched compost is more concentrated than compost; it reduces the bulk to be handled per unit of nutrient.

ii. It may increase nutrient use efficiency of added fertilizer and maintain soil organic carbon.

iii. It prevents nutrient losses due to microbial immobilization of nutrients during decomposition of organic residues and due to adsorption of cations on account of high exchange capacity of organic matter.

iv. Lesser problems in handling, storage, and transportation.

v. Offers a potential avenue for the efficient utilization of low-grade materials such as rock phosphate and waste mica (a K-bearing mineral)

Enrichment of compost can be done in two ways, namely, (i) physical addition of fertilizer materials during composting and (ii) addition of fertilizer materials with ready compost by mixing. Incorporation of fertilizers during composting leads to immobilization of fertilizers into microbial body and insertion into molecules of humic substances formed during decomposition. A substantial part of added inorganic nutrients may also be adsorbed on to exchange sites or chelated by humic substances. On the other hand, physical mixing of fertilizers with finished product of compost reflects adsorption and chelation of fertilizer elements by humic substances, which are already present in the decomposed product [13].

5.5.1 Enrichment with nitrogen

Microbial mineralization and immobilization depend on the C/N ratio of the compost. The wide C/N ratio (>30:1) plant materials require addition of mineral N to narrow down the C/N ratio for rapid decomposition including mineralization during composting. During the preparation of compost from wide C/N ratio substrates, such as straws/stubbles, incorporation of fertilizer N like ammonium sulfate or urea at 0.5–1.0% of raw materials hastens the decomposition process. Addition of nitrogenous fertilizer serves as starter. Enrichment of N during composting with inorganic N can be done up to 1.8–2.5% but cannot be improved beyond 2.5% N, because of the associated losses of N includes the production of free NH_3.

In case of ready compost, it is recommended that compost with a C/N ratio of about 20:1 should be treated with fertilizer nitrogen so as to bring the C/N ratio to <10:1 and N content >2.5%. Thus, by spraying a solution of urea on finished product of compost followed by physical blending, the N content can be increased up to 5–7%. As most of the added inorganic N remains in the fertilizer from without much of chemical or biological reaction with the manure, it is tough to understand the utility of using fertilizers to raise N content of the finished product above 5–7%.

5.5.2 Enrichment with phosphorus

Phosphorus-enriched compost can be prepared by adding 5% superphosphate, dicalcium phosphate (DCP), and rock phosphate at the time of filling of the compost pits. Due to enrichment with soluble phosphate in compost, a small amount of immobilized soluble P into microbial body may be expected. But with most plant material containing sufficient P to satisfy microbial demands during decomposition, assimilation of P from external sources is seldom needed. Addition of insoluble sources of P like low-grade rock phosphate to enrich compost is a more rational and practical approach, since solubilization of sparingly soluble P occurs during composting. Besides phosphorus, it is a source of calcium and micronutrients. Early work showed that by adding rock phosphate to farm composting materials to a thickness of about 5 mm per layer, nearly 50–70% of sparingly soluble P could be converted to soluble from which is readily available to plants. Addition of soluble fertilizer-P to finished compost provides a better scope for increasing the efficiency of fertilizer-P as well as organic-P. Thorough mixing of fertilizers with compost may reduce P-fixation. The mineralization of organic-P may also be accelerated due to increased solubility of organic-P in the presence of fertilizers. Amalgamation of compost with single superphosphate (SSP) could raise phosphorus content of the enriched compost up to 5% P_2O_5 [13].

5.5.3 Enrichment with potassium

To enrich the compost, potassium-bearing minerals like feldspars and mica can be added during composting. The availability of potassium can be improved due to the production of organic acids such as citric, tartaric, acetic acid, etc. Potassium can also be added to compost by incorporating plant materials, which contain appreciable amounts of potassium, viz., water hyacinth and banana skin, are rich source of potassium. Dry potato vines also contain about 1% potassium which can be incorporated to improve the K content in the compost [13].

5.5.4 Enrichment with bioinoculants

Addition of nitrogen-fixing bacteria and/or phosphate- and potassium-solubilizing microorganisms is one of the possible means of improving nutrient content of the final product of compost. Inoculation of *Azotobacter*, *Azospirillum*, *Clostridium*, etc. to the compost heap enhances N content by fixing atmospheric N_2. Phosphate-solubilizing bacteria such as *Bacillus polymyxa*, *Pseudomonas striata*, and fungi such as *Aspergillus awamori* can be introduced into the composting mass along with rock phosphate. These microorganisms help in solubilizing sparingly soluble inorganic phosphates due to the production of organic acids such as citric, tartaric, gluconic acid, etc. and thereby increasing the available P, both water-soluble and citrate soluble P, content of compost. Some cellulolytic and lignolytic microorganisms such as *Trichoderma viride*, *Trichurus spiralis*, *Paecilomyces fusisporus*, *and Phanerochaete chrysosporium* are used as compost accelerator to hasten the process of composting [13].

5.6 ADCO compost

This process was introduced in England in 1921. Hutchinson and Richards [14] developed an ADCO powder, used as a starter at 7.0 kg per 100 kg dry waste product. Fowler assured that this powder is prepared with various substances like ammonium phosphate, cyanamide, and urea. On the other hand, Collision and Conn prepared another powder of 27 kg ammonium sulfate, 13.5 kg superphosphate, 11.250 kg murate of potash, and 22.5 kg ground limestone and added to 1 ton dry matter for producing manure. This produced manure has characteristic resemblance with manure produced using ADCO powder. For ADCO process a plane place measuring 450 cm long and 180 cm breadth is required. First, a layer of refuse about 30 cm thick is spread at the bottom of the pit, and over this a calculated amount of ADCO powder, i.e., 7 kg per 100 kg refuse, is sprayed. Six-time addition of refuse in that pit means 1 ton refuse, and every time ADCO powder is added. The heap height should be within 180 cm, i.e., 6 feet. After completion of heap, time to time watering is done. Through aerobic composting, the manure becomes ready within 4–5 month.

Advantages: Very suitable method for making compost. Within 4–5 months proper decomposition makes good organic manure.

Disadvantages: Regular turning is required for aeration and watering for proper decomposition. It increases labor charges and cost of production.

5.7 Vermicompost

Compost prepared using earthworms is called vermicompost. Earthworms consume all type of organic matter especially green matter, retain 5–10% for their growth, and excrete the mucus-coated undigested matter called vermicast. This undigested matter undergone physical and chemical breakdown by the activity of muscular gizzard present in the worms' intestine. It is a cost-effective, time saving, and efficient process of recycling nontoxic animal and agricultural and industrial wastes. Vermicast is rich in nutrients—N, P, K, Ca, Mg, vitamins, enzymes, and growth-promoting substances. In addition, the warms do the turning and no additional turning of the compost heap is required. The efficient species of earthworms are *Eisenia foetida*, *Pheretima elongata*, *Eudrilus eugeniae*, *and Perionyx excavatus* [13].

For preparation of a good quality of vermicompost, a number of steps are followed as mentioned below:

i. Selection of earthworm: The locally available earthworm native to a particular soil and efficient for fast composting may be used for vermicomposting.

ii. Size of pit: Any convenient dimension such as 2 m × 1 m × 1 m may be prepared. This can hold 20,000–40,000 worms giving one ton manure per cycle. The pit should be base concreted as termite proof and ant proof through water drain around it. A shade of 6–8 ft height is also required for cool and ambient climate for the worms.

iii. Preparation of vermibed: A thick layer of 15–20 cm of good loamy soil above a thin layer (5 cm) of broken bricks and sand should be made. This layer is prepared on concreted floor and made to inhabit the earthworms.

iv. Inoculation of earthworms: About 100 earthworms are introduced as an optimum inoculating density into a composite pit of about 2 m × 1 m × 1 m, provided with a vermibed.

v. Organic layering: It is done on the vermibed with fresh cattle dung of 5–10 cm. The compost pit is then layered to about 5 cm with dry crop residues. Carbon-rich solid and dead substrates like sawdust, paper, and straw are mixed with N-rich natural components such as sewage, sludge, and biogas slurry to obtain a near optimum C/N ratio. Mixing variety of substances produces good-quality compost which is rich in macro, micro, and even trace nutrients. Decomposition can be accelerated by chopping raw materials into small pieces. Moisture content of the pit is maintained at 50–60% of water holding capacity. Aeration can be maintained by mixing with fibrous N-rich materials. The temperature of the piles should be around 28–30°C. Wide gap between higher or lower temperatures reduces the activity of microflora and earthworms. The normal pH of the raw materials is preferable.

vi. Wet organic layering: It is done after 1 month with moist/green organic waste, which can be spread over it. This practice can be repeated every 3–4 days as per requirement. Mixing of wastes periodically without disturbing the vermibed ensures proper vermicomposting. Wet layering with organic waste can be repeated till the compost pit is nearly full.

vii. Harvesting of vermicompost: In order to facilitate the separation of worms from vermicompost, the moisture content in the compost is brought down by stopping the addition of water around 7–10 days before maturation that ensures drying of compost and migration of worms into the vermibed. This forces about 80% of the worms to the bottom of the bed. The remaining worms can be removed by hand. The mature compost, a black, fine loose, granular humus rich material, looks like CTC tea, is removed out from the pit, dried, and packed. The pleasant earthen smell is one of the good indications of mature compost. The vermicompost is then ready for application.

The nutrient content of vermicompost varies depending on the raw materials as well as different species of earthworms used. Thus, the final product is not a single standard product. The average nutrient content of vermicompost is 0.6–1.2% N, 0.13–0.22% P_2O_5, 0.4–0.7% K_2O, 0.4% CaO, and 0.15% MgO. On an average, it contains comparable N, P, and wide C/N ratio as in FYM but less K and micronutrients than FYM. On the whole, vermicompost cannot be described as being nutritionally superior to other organic manures. Yet the unique way in which it is produced, even in the field condition, time saving, and at low cost, makes it very attractive for practical application. Unique feature of vermicompost is its rapid process of composting which takes about 60–90 days depending on the environmental conditions. The excess worms that have been harvested from the pit can be used in the other pits, sold to other farmers for compost inoculation, and may be used as animal and poultry feed or fish food [13].

6. Green manure

Green manuring is the practice of enriching soil nutrient status by growing a crop and plowing in situ or turning it into the soil as undecomposed green plant materials for the purpose of improving soil health. These crops are known as green manure crops. They improve soil physical properties and supplies nutrients particularly N, if it is a legume crop. Green manuring can be of two types.

6.1 In situ green manuring

When the green manure crop is grown and buried in the same field, it is called in situ green manuring. Most important in situ green manuring crops are sunnhemp (*Crotalaria juncea*), dhaincha (*Sesbania aculeata*), cowpea (*Vigna sinensis*), berseem (*Trifolium alexandrinum*), and Lucerne (*Medicago sativa*) [15].

6.2 Green leaf manuring

These are the plants grown elsewhere, and green leaves and tender twigs are brought to the field for incorporation. This is labor consuming. Popular green leaf manuring plants are *Leucaena leucocephala* (Subabul), *Cassia tora*, *Sesbania speciosa*, *Pongamia pinnata* (Karanj), *Pongamia glabra*, and *Gliricidia maculata* [15].

In general, green manure crops should be a legume with good nodulation, i.e., N_2-fixing capacity, fast growing, having low water requirement, and short duration, i.e., 4–6 weeks with tender leafy habit permitting rapid decomposition. Incorporation of green manure crop should be done before or at flowering stage because these are easily decomposed at this stage after which these become fibrous and take more time for decomposition.

7. Concentrated organic manures

These manures contain higher percentages of major essential plant nutrients (N, P, and K) compared to bulky organic manures (FYM and compost). They are derived from raw materials of plant or animal origin, such as oilcakes, fish manure, dried blood, bone meal, etc. Oilcakes are the residues, left after oil is extracted from oil-bearing seeds. Generally, edible oilcakes are used for animal feed, while nonedible oilcakes are used as manures. Oilcakes contain higher amounts of N than P_2O_5 and K_2O; thus, these are commonly referred to as the organic nitrogenous fertilizers. Bone meal consists of calcium phosphate together with fats and proteins. These are good sources of lime, phosphate, and N. Bone meal is a slow-acting organic-P-fertilizer resembled with rock phosphate and suitable for acid soils. Fish manure is a quick-acting manure and suitable for all soils and crops. It is available as either dried fish or fish meal or powdered fish. However, its use is restricted mainly to coastal areas where it is available easily. Guano (dried excreta of sea birds) is

Product	N (%)	P_2O_5 (%)	K_2O (%)
Plant origin			
Edible oil cakes			
Safflower (decorticated)	7.9	2.2	1.9
Groundnut	7.3	1.5	1.3
Sesame	6.2	2.0	1.2
Rapeseed/mustard	5.2	1.8	1.2
Linseed	4.9	1.4	1.3
Nonedible oil cakes			
Neem	5.2	1.0	1.4
Castor	4.3	1.8	1.3
Karanj	3.9	0.9	1.2
Cottonseed (undecorticated)	3.9	1.8	1.6
Mahua	2.5	0.8	1.8
Animal origin			
Blood meal	10–12	1.0–2.0	0.6–0.8
Meat meal	10–11	2.0–2.5	0.7–1.0
Fish meal	5–8	3.0–6.0	0.3–1.5
Guano	7–8	11–14	2.0–3.0
Slaughterhouse waste	8–10	3.0	—
Bone meal (raw)	3.0	20.0 (8% citrate soluble P_2O_5)	—
Bone meal (steamed)	—	22.0 (16% citrate soluble P_2O_5)	—
Wool waste	4–7	—	1.0–5.0
Miscellaneous			
Press mud	1.0–1.5	4.0–5.0	2.0–7.0

Table 5.
Average nutrient content in concentrated organic manures [6].

another concentrated organic manure, containing substantial amount of nutrients, particularly N and P_2O_5, but it is not produced in India [13]. Average nutrient contents in various concentrated organic manures are placed in **Table 5**.

8. Sewage and sludge

Sewage refers to the liquid portion, and sludge refers to the solid portion of the waste which originates from the city sewerage system. Raw sewage consists mainly of water carrying suspended and dissolved black colored solid organic matter which may pollute water bodies (rivers). For that reason, it is treated by some means to reduce the organic matter load before it could be disposed off safely. During siphoning at sewage treatment plant, the sludge portion settles down and is separated from the liquid portion (sewage). The sewage can be used for irrigation purposes, while sludge can be used as manure as it contains large amount of plant nutrients. It has been estimated that available sewage of big cities in India could annually contribute around 1.2 Mt of N, 1.0 Mt of P_2O_5 and 0.8 Mt of K_2O. However, it contains excessive organic and N loading, and repeated application of untreated sewage water can result in soil sickness due to anaerobiosis and imbalance in C/N and C/P ratio and clogging of soil pores by colloidal matter and bacterial contamination of vegetables grown using them. Treated sewage water, after dilution (1:1) with good-quality water, can increase yield of crops. The main disadvantage of using sewage and sludge in agriculture is its heavy metals content, particularly Pb, Cd, Cr, and Ni depending on the source of industry from where the sewage and sludge originates. Thus, repeated application of sewage tends to increase the concentration of metals in soils and their availability to plants, which in turn could get into our food chain [16].

9. Distillery effluents (spent wash)

It is the by-product of manufacturing of ethyl alcohol from molasses. It contains considerable amounts of organic matter and plant nutrients especially K and S and appreciable amounts of N and P. This can be applied as irrigation water and as an amendment (for alkali soils). However, because of its high organic load, it may results biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in water. For that reason, they are unsafe for direct application on to agricultural lands. Spent wash can, however, be safely applied to different crops after suitable dilution and has been reported to increase yield of several crops. Treatment of this effluent through biomethanation digesters reduces the organic matter load but still carries considerable organic and salt load, making its disposal a problem [15].

10. Conclusion

Composting is a natural phenomenon and pervasively relates with organic farming. Accelerating the quality and speed of compost is a scientific phenomenon and irrevocable for sustainable growth and development of agriculture without any toxic effect on environment and livelihood.

It is established that any single method or technique of composting cannot be recommended for all areas and conditions. Also area-wise economic, climatic, social, and other factors will dictate the best method for that area. The efficiency of composting technique also depends on the type and amount of substrate(s) and the rearing techniques. However, it is hoped that the described methods will aid economic improvement in many areas and help establishing sustainable agriculture for the betterment of future. In consideration of time and quality, vermicomposting seems to be the best technique for composting and much more economically viable for the sustainable growth and development of modern agriculture. Vermicomposting technique is also worm and site specific. After long-term scientific experiments, *Eisenia fetida* is considered as the world's most efficient species having the capacity to acquaint with wide environmental condition. The compost production capacity of this worm is higher than other species, and so this species is widely accepted for vermicomposting.

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