Training Material on Composting and Vermicomposting

*Compiled by Ecosan Services Foundation (ESF)
and seecon gmbh in the context of the
Innovative Ecological Sanitation Network India
(IESNI)*

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1. Introduction:

Ecological sanitation (ecosan) represents a holistic approach towards ecologically and economically sound sanitation, and is a systemic approach as well as an attitude. It is an alternative approach to overcome the limitations and disadvantages of conventional sanitation systems. The ecosan paradigm in sanitation is based on an ecosystem approach, which focuses on recycling of nutrients. Human excreta and grey water from households are recognized as a resource rather than waste and therefore human excreta have to be made available as raw materials for supporting agriculture.

The applied technologies may range from natural wastewater treatment techniques to compost toilets, simple household installations to complex, mainly decentralized systems (Otterpohl, 2004). Therefore, ecosan is not just a poor people solution with low standard but having more a number of appropriate solutions for different specific local situations. Composting of human waste is one of the important and necessary steps to convert the untreated or partially treated waste in to organic fertilizer. Major advantages of ecosan are as follows:

- Efficient utilization of nutrients present in the excreta,
- Reduce the consumption of fresh water,
- Reduces the health risks,
- Reduce the water bodies pollution,
- Prevents the degradation of soil fertility,
- Optimizes the management of nutrients and water resources.

2. Impact of the Current Sanitation Practices:

The water based sanitation system we're currently using requires about 20 - 50% of our daily water consumption for flushing the toilet. All the water is used for flushing about 0.2 - 0.5 kg of human waste and most of the time we are using the precious fresh water rather than recycled water. The large quantities of water for transport the waste are required only, because we have treatment plant far away from generation point. The current practices impose two things; first increase in the volume of wastewater and the second pathogens are carried. In the current sanitation practices we are disposing the untreated or partially treated wastewater into the water bodies or into land. The major consequences are scarcity of water and loss of organic fertilizer which have further consequences on the environment.

3. Chemical fertilizer vs. organic fertilizer:

3.1. Role of Nutrients for Plant for Plant Growth:

The plants need the 16 essential nutrients (carbon, hydrogen, oxygen, nitrogen, phosphorous, potassium, magnesium, calcium and sulphur, iron, zinc, copper, manganese, boron, chlorine and molybdenum) for survivability and growth. All plants need oxygen, carbon and hydrogen, which they get from the air, sunlight and water. Other elements are divided into major elements (primary as nitrogen, phosphorous, potassium and secondary as magnesium, calcium and sulfur) and trace elements (such as iron, zinc, copper, manganese, boron, chlorine and molybdenum).

Nitrogen is essential constituents of metabolically active compounds such as amino acids, proteins, enzymes and few non-proteins compounds.

Nitrogen is needed for leaf and stem growth, and it gives a dark green color to plants. The level of nitrogen added to the soil is important since it affects the plants' access to other nutrients such as phosphorous and potassium. Nitrogen is also important from the point of view of nutrition as it increases the protein content of some foods and feed crops.

Phosphorous is structural components of all membranes chloroplasts, mitochondria and constituents of sugar phosphate. It also plays an important role in energy transformation and metabolic processes in plants. Phosphorous helps make plants more drought resistant and hardy. It hastens maturity, helps seed and fruit formation, and stimulates root growth. It also helps legumes grow and form nodules.

Potassium plays an important role in the maintenance of cellular organizations by regulating permeability of cell membranes. It activates the enzymes in protein and carbohydrate metabolism. Potassium also develops the resistance to plants against fungal and bacterial disease. Potassium increases resistance of plants to disease, creates winter hardiness and drought resistance, and produces stiff stalks and stems to reduce water logging. It also increases grain plumpness as well as growth of fruit and root vegetables.

Calcium is constituents of the wall an activator of different plant enzymes and necessary for cell membranes. It improves the intake of other plant nutrients specially nitrogen and trace element by correcting the soil pH.

Magnesium is a constituent of chlorophyll and chromosome. It also works as a catalyst for enzyme. It regulates the uptake of nitrogen and phosphorous from the soil.

Sulfur is required to synthesize the sulfur containing compounds such as amino acids and proteins and increase the oil content in oil bearing plants. It improves the root growth and stimulates seed formation. It is also known as master nutrients for oil seed production.

Role of trace element is equally important as major element for plant growth even than they required in trace quantity. Trace element work as a catalyst or closely linked with catalyst processes for enzyme activity or oxidation reduction processes.

3.2. Chemical fertilizer and their Impact:

In current practices we are using the chemical fertilizer to fulfill the plant nutrients requirement which have a serious impact on the soil and water bodies. The salinity of soil is one of the major threats by using utilizing excessive chemical fertilizer. The chemical fertilizers have a serious impact on as follows…..

- Loss of soil fertility (reducing food production),
- Plants can utilize only 20 - 30% nutrients, the balance either evaporates or is washed into water bodies (i.e. ground water, surface waters, etc.),
- Ground water and surface water pollution,
- Destruction of marine life (declining fish populations, reducing a major source of protein for human consumption),
- Loss of biodiversity on land and in water,

- Global warming and ozone depletion, when nutrients form gases that escape into the atmosphere,
- They are either sterile or have negligible microbiological activity,
- Salinity of soil.

3.3. Advantages of Application of Organic Fertilizer:

The application of compost has been reported to be efficient enough in restoration of the soil. The addition of organic matter even in a little to the soil have shown a positive effect on the physical, chemical and biological soil properties……..

- ✓ Improves soil structure
- ✓ Improves pore space
- ✓ Increases water-holding capacity
- ✓ Better water supply for crops
- ✓ Increases the diversity of micro-organisms
- ✓ Multitude of biochemical processes
- ✓ Increases the capacity to buffer pH and pollutants
- ✓ Better storage and exchange capacity for (micro) nutrients
- ✓ Reservoir of N P K S steadily released by mineralization

Increase in soil organic matter (SOM) improves overall soil quality influencing many soil functions that SOM also. Soil organic matter (particularly > 5µm), play important decisive role in orientation of soil clay particles, soil compaction and hence regeneration of its structure

Composting and vermicomposting is the best and efficient method to produce the organic fertilizer from human excreta.

Table 1: Comparison of Chemical and Organic Fertilizer

	Criteria for Comparison	Chemical Fertilizers	Organic Fertilizer
1	Primary Nutrients (Nitrogen, Phosphorus and Potassium)	Generally separate fertilizer required for each element	Contains all elements
2	Secondary Nutrients (Calcium, Magnesium and Sulphur)	Not available	Available
3	Trace Nutrients (Zinc, Iron, Boron, Manganese, Copper, Molybdenum and Chlorine)	Not available	Available
4	Active Microbial Biomass	Not available	Available
5	pH	Disturb soil pH	Helps in the control of soil pH
6	Salinity	Create the salinity	Reduce the salinity
7	Electrical Conductivity	Increase	Balance
8	Organic carbon	Not available	Available
9	Moisture Holding capacity of Soil	Reduces	Increases
10	Soil Texture	Damages	Improves
11	Plant growth hormones	Not available	Sufficient quantity helps in better growth and production

4. Biological degradation/decomposition of organics:

There are two distinct pathways of biological degradation/decomposition of organic material:

1. Anaerobic digestion
2. Aerobic digestion:

4.1. Anaerobic digestion:

Anaerobic digestion is the break down of organics in the absence of oxygen under controlled conditions. In an anaerobic process fermentation results in the formation of ammonia-like substances and hydrogen sulfide, this smells like rotting eggs. The carbon content of the material is released as biogas containing methane, carbon dioxide and other gases as per following equation.

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 2CH_4 + 393kJ \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad 1$$

Anaerobic digestion is more suitable for waste, which has a high degradable organics. It requires viable bacterial population of different species those are able to degrade targeted organics and thorough mixing for efficient substrate conversion. This technology is appropriate for the organic materials if biogas retrieval is preferred. However, it is not recommended for composting of mixed domestic wastes. If recovery of biogas is not provided for, the generation of odorous gases can act against the installation of anaerobic systems in populated areas.

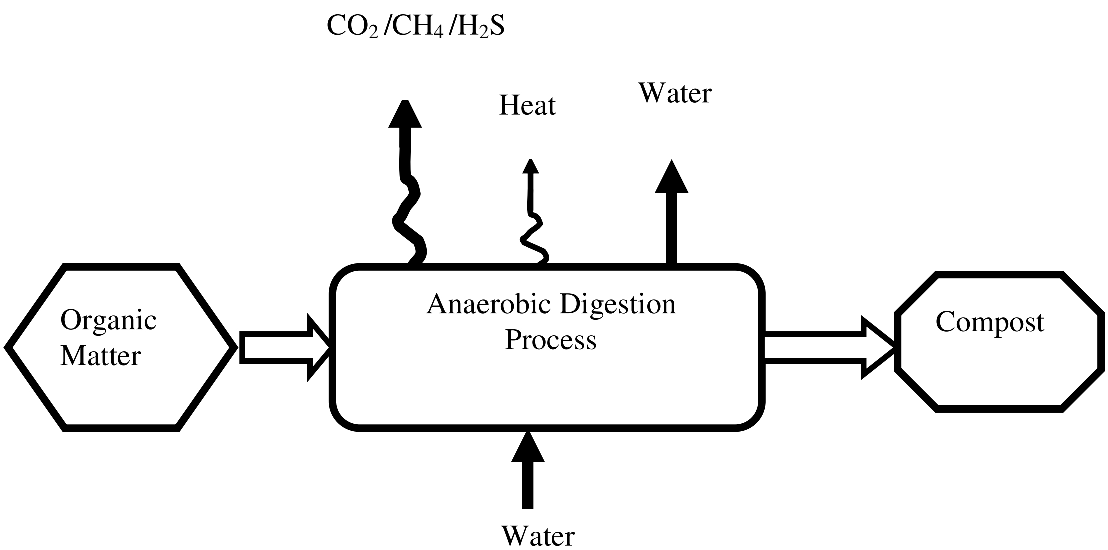

Figure 1: Process Diagram of Anaerobic Digestion Process

4.2. Aerobic Digestion:

Aerobic digestion refers to the biological degradation, vigorous humification and pasteurization of organic residues with help of air breathing microbes (bacteria, fungi and actinomycetes) under controlled aerobic conditions. It involves the action of mesophilic-exothermic microbes (Equation 2) followed by thermophilic microorganisms that thrive in increased temperature (more than 60 ^{0}C) and if correctly managed, can destroy pathogens. Biodegradable organic matter is mineralized while carbon dioxide, ammonia, water and heat are liberated (Figure 2), and the residual organic components are converted mainly to humic acids and get stabilized. Finally, the heterogeneous waste is transmuted into homogeneous, valuable, stabilized and humus rich product organic fertilizer.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2840kJ \quad \dots \quad \dots \quad \dots \quad \dots \quad 2$$

Compost is an excellent product, retaining most of the original nutrients that can be beneficially applied to soil to increase its organic and nutrient contents, which improves soil structure and fertility. Primarily, there are four parameters considered for evaluation of process performance and compost quality, namely, volatile solids, respiration rate, germination tests and pathogen indicators

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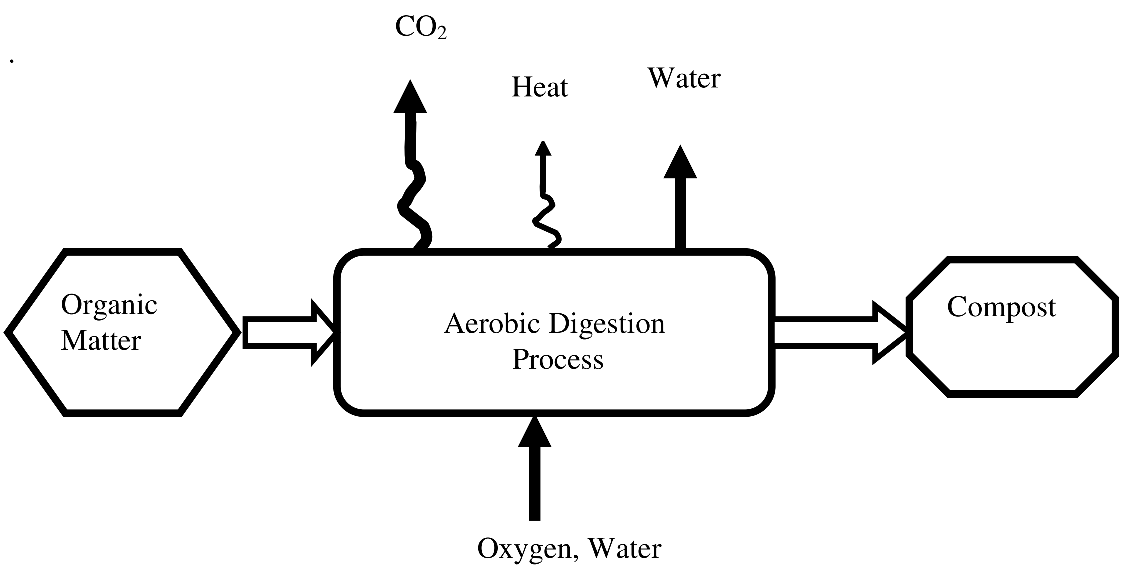


Figure 2: Process Diagram of Aerobic Digestion Process

5. Composting:

5.1. Purpose of Composting:

Composting does not mean to complete decomposition of all degradable organic materials, but to degrade only putrescible that could otherwise create odors and nuisance in the environment. Contrary to general belief, composting process also releases a few odorous gases even in most favorable conditions.

5.2. What Happens During Composting:

The easily degradable carbon is converted in to carbon dioxide and process does not stop at a particular point. Material continues to break down until the last remaining nutrients are consumed by the last remaining organisms and until nearly all of the carbon is converted to carbon dioxide. However, the compost becomes relatively stable and useful long before this point. Compost is judged to be "done" by characteristics related to its use and handling such as carbon to nitrogen ratio, oxygen demand, temperature and odor. The carbon, chemical energy, protein and water in the finished compost are less that that of the raw materials. The volume of the finished compost is 50% or less of the volume of the raw material.

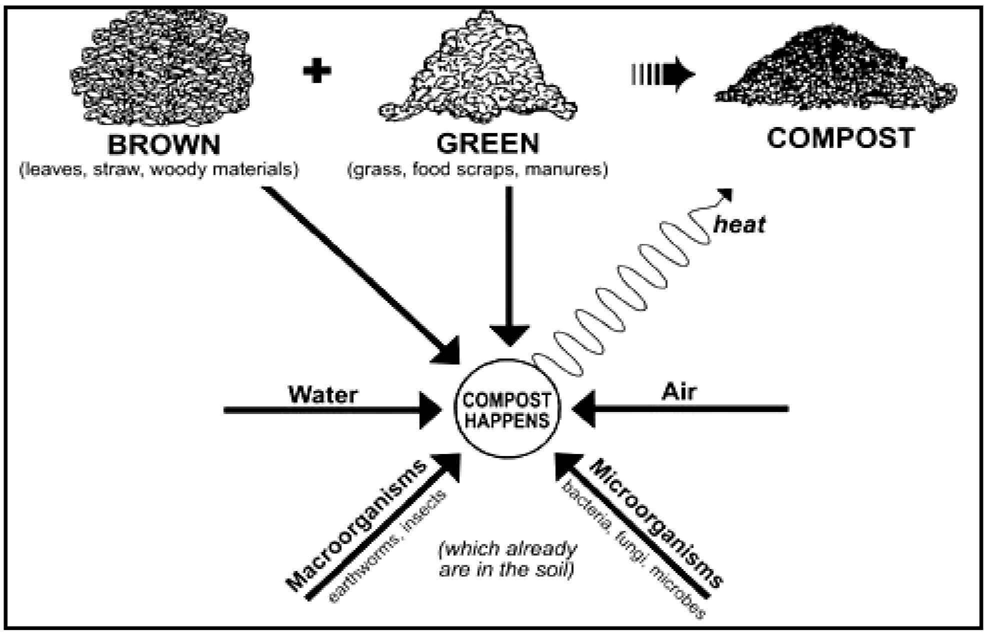


Figure 3: Process Flow Diagram of Composting Process

5.3. Factors Affecting the Composting Process:

All organic material will eventually decompose. The speed at which it decomposes depends on these factors:

1. Carbon to nitrogen ratio of the material,
2. Moisture Content,
3. Aeration, or oxygen in the pile,
4. Temperatures,
5. Amount of surface area exposed,
6. pH

5.3.1. Carbon-to-Nitrogen Ratio:

Carbon and nitrogen are the two fundamental elements in composting, and their ratio (C/N) is significant. The bacteria and fungi in compost digest or "oxidize" carbon as an energy source and ingest nitrogen for protein synthesis. Carbon can be considered the "food" and nitrogen as the digestive enzymes.

The bulk of the organic matter should be carbon with just enough nitrogen to aid the decomposition process. A C/N-ratio of roughly 30 parts carbon to 1 part nitrogen (30:1) by weight should be satisfactory for efficient and rapid composting. The composting process slows if there is not enough nitrogen, and too much nitrogen may cause the generation of ammonia gas which can create unpleasant odors. Leaves, sawdust are a good source of carbon; fresh grass, and manures are sources of nitrogen.

5.3.2. Moisture:

Microorganisms can only use organic molecules if they are dissolved in water, so the compost pile should have a moisture content of 60-80% of water holding capacity. If the moisture content falls below 40% of water holding capacity the microbial activity will slow down or become dormant. If the moisture content exceeds 80% of water holding capacity, aeration is hindered, nutrients are leached out, decomposition slows, and the odor from anaerobic decomposition is emitted. The "squeeze test" is a good way to determine the moisture content of the composting materials. Squeezing a handful of material should have the moisture content of a well wrung sponge. A pile that is too wet can be turned or can be corrected by adding dry materials.

5.3.3. Temperature:

Microorganisms generate heat as they decompose organic material. A compost pile with temperatures between 90 and 140 ^{O}F (32-60 ^{O}C) is composting efficiently. Temperatures higher than 140 ^{O}F (60 ^{O}C) inhibits the activity of many of the most important and active organisms in the pile. Given the high temperatures required for rapid composting, the process will inevitably slow during the winter months in cold climates. The high temperature in pile significantly helps in pathogen reduction. Compost piles often steam in cold weather. Some microorganisms like cool temperatures and will continue the decomposition process, though at a slower pace.

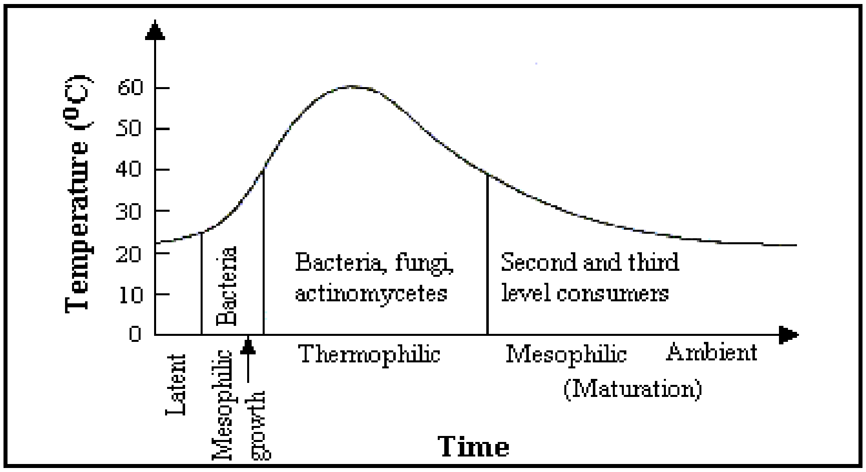


Figure 4: Patterns of temperature and microbial growth in compost piles (Polprasert, 1996)

5.3.4. Aeration:

The decomposition occurring in the compost pile takes up all the available oxygen. Aeration is the replacement of oxygen to the center of the compost pile where it is lacking. Efficient decomposition can only occur if sufficient oxygen is present. This is called aerobic decomposition. It can happen naturally by wind, or when air warmed by the compost process rises through the pile and causes fresh air to be drawn in from the surroundings. Therefore composting systems or structures should incorporate adequate ventilation.

Turning the compost pile is both, an effective means of adding oxygen and bringing newly added material into contact with microbes. It can be done with a pitchfork or a shovel, or a special tool called an "aerator," designed specifically for that purpose. If the compost pile is not aerated, it may produce an odor symptomatic of anaerobic decomposition.

5.3.5. Surface Area:

Decomposition by microorganisms in the compost pile takes place when the particle surfaces are in contact with air. Increasing the surface area of the material to be composted can be done by chopping, shredding, mowing or breaking up the material. The increased surface area means that the microorganisms are able to digest more material, multiply more quickly, and generate more heat. It is not necessary to increase the surface area when composting, but doing so speeds up the process. Insects and earthworms also break down materials into smaller particles that bacteria and fungi can digest.

5.3.6. pH:

The level of pH in the waste depends upon the decomposition rate and characteristics of feed material. The release of organic acids may decrease the pH and production of ammonia from nitrogenous compounds may raise the pH. At higher pH levels, more ammonia gas is generated and may be lost to the atmosphere. A pH value between 6.5 and 8.5 is optimal for compost microorganisms. As bacteria and fungi digest organic matter, they release organic acids.

5.4. Decomposing Organisms:

Decomposing organisms are all the micro-organisms and larger organisms involved in breaking down organic material. Bacteria are the primary decomposing micro-organism. They arrive with the organic material, and start the process by breaking down the organic material for their own food. Bacteria grow and multiply while conditions are optimum for them, and die off as they create conditions more favorable for others. Bacteria, actinomycetes and fungi all consume waste directly and are known as first level decomposers (Figure 5: Food Web of the Compost Pile Diagram). They are assisted by larger organisms - earthworms, beetle mites, sowbugs, whiteworms, and flies - which also consume waste directly. First-level decomposing micro-organisms are eaten by second-level decomposers such as springtails, mold mites, feather-winged beetles, protozoa and rotifers. Third- level decomposers eat both first and second-level decomposers and include centipedes, rove beetles, ants and predatory mites. Organisms at each level of the food web help keep populations of the lower levels in check.

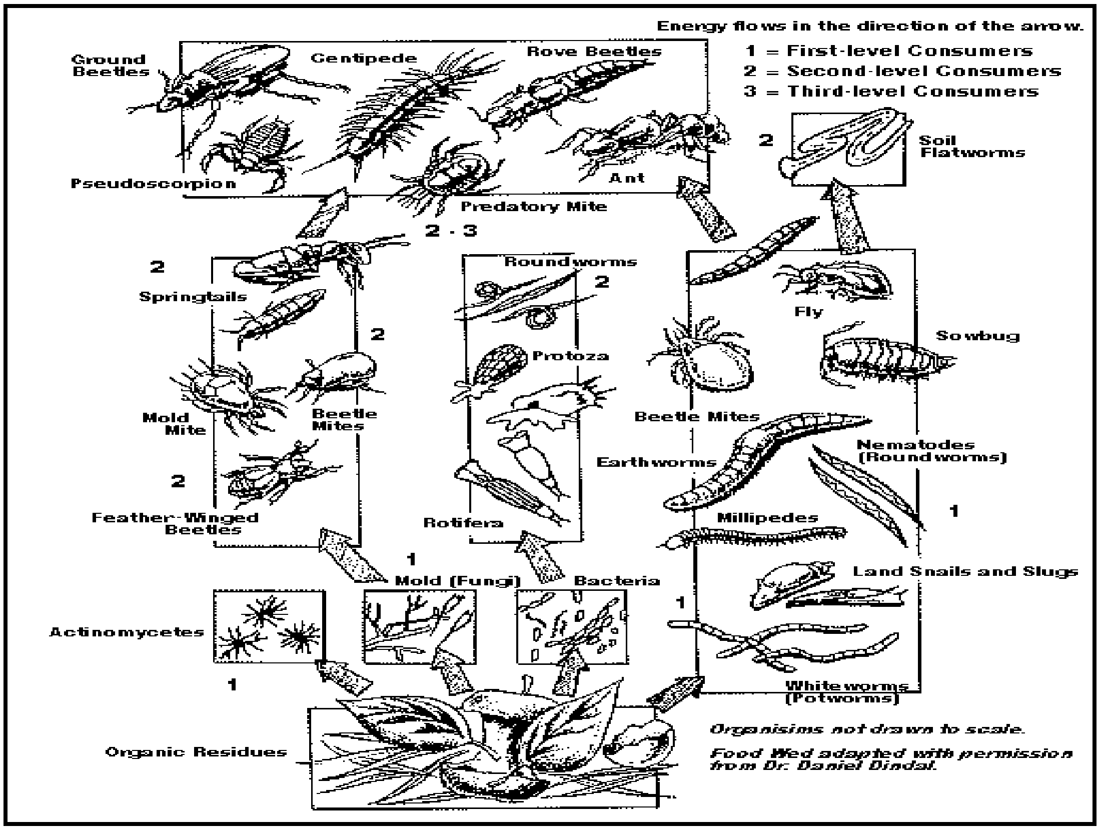


Figure 5: Food Web of the Compost Pile

5.4.1. Bacteria:

Bacteria are abundant. There may be millions in a gram of soil; you would need 25,000 laid end to end on a ruler to make 2.54 cm (one inch). They exist on every piece of organic matter even though you can't see them. When exposed to organic tissue, bacteria "invade" - eating and digesting the tissue, breaking it down into simpler forms for other bacteria and organisms to consume. As a group, bacteria are considered to be nutritionally diverse, which means that they can eat almost anything, living or dead. Bacteria require both nitrogen and carbon that comes from organic materials. The more variety, the greater likelihood they will find a blend of essential nutrients. Bacteria use carbon (C) as a source of energy and, by oxidizing carbon, generate heat and carbon dioxide (CO_2). Nitrogen (N) is their main source of protein, which is needed for body building and population growth.

5.4.2. Actinomycetes:

Actinomycetes are a higher form of bacteria, similar to fungi, and second in number to bacteria. They are especially important in the formation of humus. They liberate carbon (C), nitrate nitrogen (NO_3) and ammonium nitrate (NH_4), making nutrients available to plants.

5.4.3. Fungi:

Fungi are smaller in number than bacteria or actinomycetes, but larger in body mass. Fungi live on dead or dying material and obtain energy by breaking down organic material. Role of fungi is also important in lignin and tannin rich organic matter for break down these substances.

5.5. Limitations of composting:

Composting has been widely accepted as an eco-friendly productive way to manage the waste materials, however, it is a slow process taking at least six months and requiring frequent mixing with possible losses of nutrients (NH_3). Though composting passing through thermophilic stage effectively reduces pathogens, however, absolute removal is very difficult.

6. Vermicomposting:

Vermicomposting is an ecobiotechnical stabilization process, which involves the breakdown of organic waste and in contrast to microbial composting it involves the joint action of earthworms and mesophilic microorganisms and does not involve a thermophilic stage. Worms require environment that is encouraging for microbial degradation and to maintain biochemical processes that enhance microbial decomposition. They add various intestinal microflora in matrix, moreover gut enzymes play dominant role in this process (Whiston and Seal, 1988). Further, earthworm also enhances microbial activities by improving the environment for microbes (Syers *et al.*, 1979; Mulongoy and Bedoret, 1989). It turns wastes in more homogenized, nutrient rich and well stabilized product. Studies have shown that vermicomposting is an effective method for treating pathogen rich wastes (Eastman, 1999; Eastman *et al.*, 2001; van Zoest, 2002)

There are several indicators for performance evaluation of vermicomposting process, like, worm survival and biomass growth, and worm population growth. The quality of vermicompost is generally evaluated same as in case of compost. Since worm grazes the pathogens, vermicomposting potentially ensures the removal of pathogens, if effectively commenced even for shorter period of a week. Thus it is recognized as 'Class A' stabilization process by the USEPA (Eastman *et al.*, 2001). The waste material treated in microbial composting is less moist, as higher moisture content reduces the interstitial air passage. This can lead to process failure, as it become anaerobic. In vermicomposting, higher humidity can be tolerated as the worm burrows act as channels for air passage.

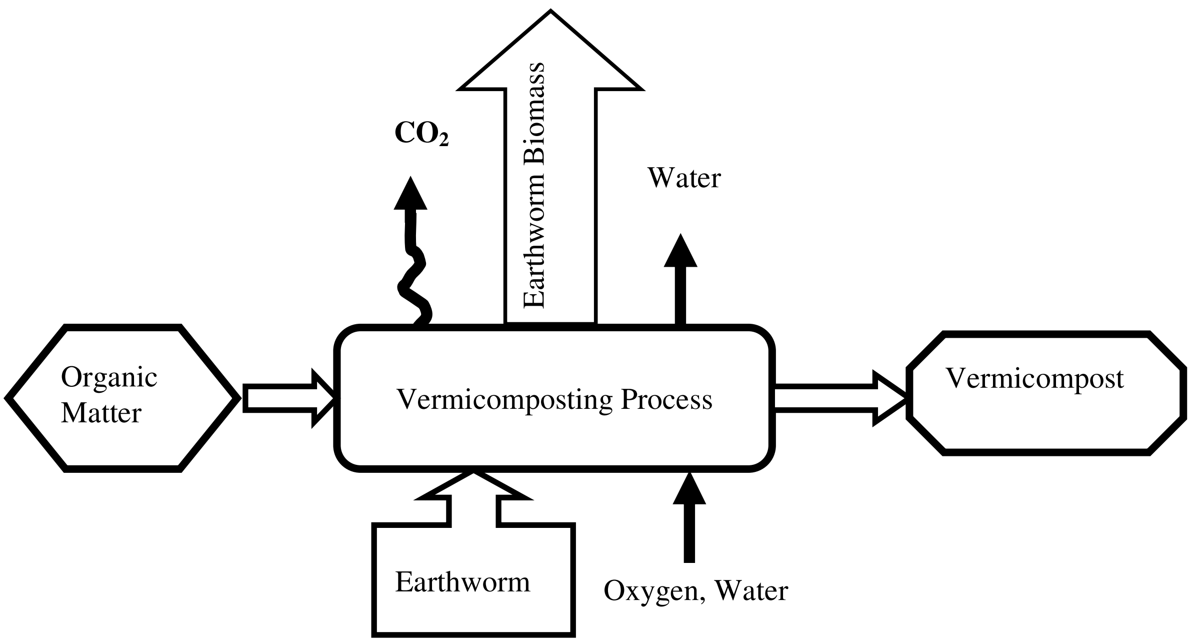


Figure 6: Process Diagram of Vermicomposting Process

6.1. Earthworms:

Earthworms have been known for many centuries as soil forming organisms that inhabited almost all part of the earth. They have been mentioned in history dating to the times of Aristotle (about 330 B.C.). Earthworms, including composting worms, are terrestrial invertebrates that belong to kingdom Animalia, phylum Annelida, class Clitelatta and subclass Oligochaetae. The two most important families of terrestrial Oligochaeta are the Megascolecidae and the Lumbricidae. The Megascolecids comprise more than half of the known species widely distributed in Asia, Australia and the Pacific Oceanic Islands; whereas Lumbricidae is important for human welfare and natively spread in USA and Europe, however, presently found all over the world (Edwards and Lofty, 1976; Edwards and Bohlen, 1996).

There are significant differences among worms of different groups in size, shape and pigmentation, burrow construction, food source, life span and working depth in the soil profile etc. Earthworm may be of different colors e.g., red, greenish or whitish depending on the presence or absence of pigment (Edwards and Lofty, 1976). The pigments are mainly porphyrins, probably breakdown products of the chloragogen cells (Stephenson, 1930). Earthworms do not have eyes, ears and nose so can not see, smell and hear. However, they can sense heat, light, movement and vibrations through the skin besides breathing. Worms are photonegative, respond to the intensity of light (Howell, 1939) and UV radiation that causes mortality to them (Finstein, 1992; Farrel, 1997). Worms are less sensitive to moderate radiant heat than to a bright light (Jefferies and Audsley, 1988; Fraser-Quick, 2002) but very sensitive to contact (Jamieson, 2000; Jensen, 2000; Slocum, 2000a, b). Worm stops moving on touch and the response is so strong that overcome even light stimulation. With the same senses they are active and keep on rearing when kept on a surface until find a suitable crevice/crack/burrow.

6.1.1. Biology of earthworm:

The earthworm has a cylindrically shaped, segmented body that tapers off at both ends. Each segment is a separate fluid-filled compartment surrounding a central digestive tract or gut, which runs the length of the worm's body (Figure). Rings that surround the moist, soft body allow the earthworm to twist and turn, especially since it has no backbone. With no true legs, bristle (setae) on the body move back and forth, allowing the earthworm to crawl. Worms have a brain and five hearts including other major organ systems in the head end. They have neither eyes nor ears but do posses light sensitive cells and feel vibrations. Direct sunlight is very harmful to earthworms. One hour's exposure to strong sunlight causes partial-to-complete paralysis and several hours are fatal. Earthworms do not have lungs but they need oxygen to survive. A worm breathes when oxygen from the air or water passes through its moist skin into the blood capillaries. If the body covering dries out, the worm suffocates.

Earthworm ingests food through a soft mouth with a kip that can seize or grasp whatever the worm is trying to eat. The throat or pharynx can be pushed forward to help pull matter in. They have no teeth so they coat their food with saliva, which makes it softer and easier to digest. After the food is swallowed, it passes through the esophagus to the crop and then to the gizzard. Food ingested by worms is grind up to a particle of 1-2 micron size by contractions of muscles in the gizzard with the help of grinding material such as sand or topsoil.

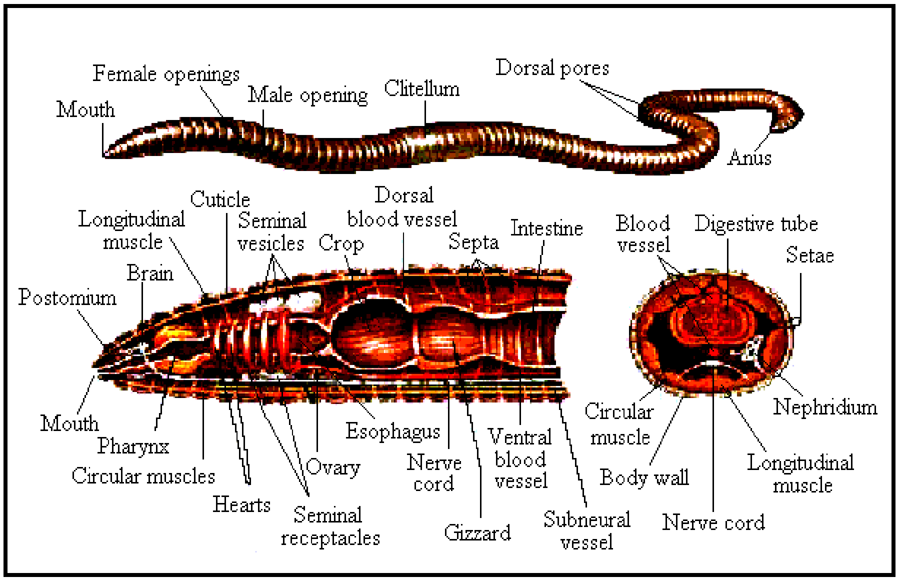


Figure 7: Anatomy of the earthworm

6.1.2. Life cycle and population:

Earthworms are hermaphrodite, which means each worm is both male and female. However, each worm must still mate with another worm of its species in order to reproduce. During mating, any two adult worms can join together to fertilize each other's eggs. Fertilized egg contains in a mucous tube secreted by the clitellum that slips over its head and then into the soil through its mouth as an egg-case or cocoon. These cocoons are about the size of a match stick head and change color as the baby worms develop, starting out as pale yellow and when the hatchlings are ready to emerge, cocoons are reddish-brown.

Table 2: Comparison of Lifecycle and Growth of Different Worm Species

Species of Earthworm	Biomass Production, g/wk	Average Reproduction Rate, worm/wk	Egg Maturation Period, d	Cocoon Hatching, d	Period to Attain Maturity, d	Mean Mature Weight, g
Eisenia fetida	0.68	10.4	85-49	32-73	53-76	0.55
Eudrilus eugeniae	5.76	6.7	43-12	13-27	32-95	4.3
Perionyx excavatus	6.3	29.4	44-71	16-21	28-56	1.3
Dendrobaena veneta	0.16	1.4	97-214	40-126	57-86	0.92

(Edwards, 1988; van Zoest, 2002)

Number of cocoons and hatchling period varies for each species and depend upon the environmental conditions. The lifespan of the earthworm in the wild is not certain, but researchers estimate a normal lifespan of about 3 years. The earthworm population is self controlled and limited by available food, space, and environmental conditions.

6.1.3. Classification of earthworm:

There are more than 1800 known species of earthworm (Minnich, 1977) and these can be subdivided in three groups. The morpho-ecological groupings described by Bouche (1977), relate to several factors including general size, shape and pigmentation, burrow construction, position in the soil profile, source of food and reproductive potential. The three group of earthworm are:

1) ***Epigeics-*** These are surface dwellers serving as efficient agent of communication and fragmentation of leaf litter, have a small body size and exhibit a high reproductive rate, They have no effect on the soil structure, as they cannot dig into the soil, for example *Eisenia foetida* (Brandling, Red wiggler or manure worm), *Lumbricus rubellus* (Red worms). These are 'muck' or compost worms which live within organic material.

2) ***Endogeics-*** These create horizontal branching burrows within the soil deriving nutrition from the organically rich soil they ingest. They have major impact on the decomposition of dead plant roots, these worms are important in soil formation process such as mixing and aeration. They have variable body size and are weakly pigmented, e.g. *Allolobophora chlorotica* (green worms) *Aporrectodea caliginosa* (grey worm).

3) ***Anecics-*** These are deep burrowing, tends to make vertical burrow up to 3 feet in depth, have a large body size, are strongly pigmented, show surface feeding and casting behavior, and exhibit a low reproductive rate in the field, for example, *Aporrectodea longa* (black headed worms), *Lumbricus terestris* (lob worms).

6.1.4. Species suitable for processing organic wastes:

Although there are literally thousands of species of earthworms, only a few have been used on a wide scale and researched adequately for use in organic waste processing. The species used most commonly include *Eisenia foetida* (Red wiggler), *Lumbricus rubellus* (Red worm), *Eisenia Andrei* (Red tiger), *Perionyx excavatus* (Blue worm), *Eudrilus eugeniae* (African nightcrawler), *Enchytraeids* (White worm), *Dendrobaena veneta* and *Perionyx hawayana*. Although these species can be used for vermicomposting, *Eisenia foetida* and *Lumbricus rubellus* are the most popular because of the ease of replicating the environmental conditions they prefer. Among all the species that have been researched adequately, *Eisenia foetida* has been proved best for processing organic waste (Edwards and Bater, 1992), and the growth and reproduction patterns of this species have also very fast.

Figure 8: Species of Red Worms

Eisenia foetida is an epigeic worm that prefers to live in organic manure or compost. It is widely known as Red wiggler or Manure worms or Brandling worms. It can process large amounts of organic matter and, under ideal conditions, can eat its body weight each day. Under perfect conditions a mature breeder produces a cocoon every 7 to 10 days. It takes about 3 weeks development in the cocoon for one to several baby worms to hatch. The newly emerged worms look just like the grown-ups, only lighter in color and much smaller. They will mature to breeding age approximately 60 to 90 days.

6.2. Microbial biomass responsible during the vermicomposting:

It takes more than just the worms to make vermicompost. The worms eat, chew and churn up the waste. The other organisms which accompany them also break it down. A simplified description of the overall mechanism is described below:

1. The worms ingest organic matter, fungi, protozoa, algae, nematodes and bacteria. This is passed through the digestive tract. The majority of the bacteria and organic matter pass through undigested (although the organic matter has been ground into smaller particles). This forms the casting along with

metabolite wastes such as ammonium, urea and proteins. The worms also secrete mucus, containing polysaccharides, proteins and other nitrogenous compounds. Through the action of eating food and excreting their casts, worms create "burrows" in the material. This in turn increases the available surface area and allows aeration.

2. There is an abundance of oxygen and nitrogenous compounds (urea, proteins and NH_3) in the excreta (vermicast) and mucus secreted from the external tissues of the worms. Some bacteria require oxygen (aerobic bacteria) whereas some object to oxygen and prefer its absence (anaerobic bacteria). Anaerobic bacteria are responsible for the stench from stagnant drains, refuse sacks and landfill sites. With the aerobic conditions in vermicompost, aerobic microbiological growth increases. It is believed that the initial burst of microbiological activity mainly consists of nitrogen fixing bacteria, nitrification bacteria, and to a lesser extent, aerobic bacteria. This is based upon previously established information that burrow walls have a high proportion of the total nitrogen fixing bacteria and that casts have higher concentrations of soluble salts and greater nitrifying power. Accompanying this microbiological growth is the breakdown of organic nitrogen compounds to ammonia and ammonium. The good news is that the sweet smelling aerobic process overcomes the ugly smell of anaerobes. That is why worm compost piles (properly fed and maintained) smell so nice.
3. The whole process consumes organic matter and creates a ruffled surface in the burrow walls. The large surface area and improved aeration results in favourable conditions for obligate aerobes (such as Pseudomonas spp., Zoogloea spp., Micrococcus spp. and Achromobacter spp.). The continued growth of the microbiological population continues to increase the rate of decomposition of the material. Air flows through the material more readily, minimizing the likelihood of anaerobic biochemical reactions occurring. This minimizes the formation of sulfide and ammonia gasses, odors that are typically present if anaerobic conditions are established. Objectionable odors disappear quickly, due to microorganisms associated with the vermicast

6.3. Advantages of Waste Management by Vermicomposting:

Composting is an effective 'zero waste' method for treating organic wastes, which follows nature's way of recycling. There are several advantages of composting such as; a safe treatment option for high nutrient waste and the production of natural fertilizer as an end product. Aerobic composting is controlled and rapid while anaerobic composting is slow. However, it is high energy intensive process as requires continuous air supply. Aerobic conditions in vermicomposting is controlled and managed by earthworms, whereas man power, electrical energy and expensive engineering system are required for aerobic composting (Table 3).

Table 3: Evaluation of Parametric Controls during the Processes

Processes Parameter	Aerobic Composting	Vermicomposting
Aeration/Turning	By mechanically/manually	By worms
Shredding/Grinding	No control	Processed by worms
Microorganism	No control	Control by worms
Level of pH	No control	Control by worms
Curing	Always required	Not required
Pathogen control	By thermophilic stage	By worms grazing
Feed Composition	50% each of green and brown waste	Combination not required
Conditioning	Required	Not required
Product quality	Good	Better

Vermicomposting is in conservative side of resources like water, energy and land required for treatment of per unit of biowaste as compared to aerobic composting. Vermicomposting is rapid, low cost and sustainable alternative for organic waste treatment managed by earthworms, with the added advantage of more aesthetic, plant nutrients, humic acids and PGRs enriched compost in the slow-release form. The worm casts hold nutrient for a longer period without adversely impacting the environment.

Vermicompost requires no curing (as traditional composted materials do) as it is already populated with beneficial microorganisms. The overall time required (and hence the cost) for processing is therefore greatly reduced, and the process produces no toxic by-products or waste. The vermicompost itself is highly valued by gardeners all over the world and has a significant market value. Vermicompost dramatically improves soil structure, texture, aeration, fertility, water holding capacity and soil ecology. This replaces valuable nutrients taken out of the soil when crops are harvested. Adding compost to soil aids in erosion control and stimulates healthy plant-root developments. Worm casts or vermicompost are not only rich in plant nutrients, but also rich in many enzymes, plant growth regulators, bacterial density and shows higher microbial and enzymatic activities than the surrounding soil. Vermicompost rich in high quality organics (humus) may be used as organic amendments.

Both composting and vermicomposting are biological processes. All the chemical reactions and physical changes occur in the composting due to bioactivities of active organisms. Difference in key role playing organisms differentiates microbial composting from vermicomposting because different organisms have distinguished characteristics and requires distinct habitat and need for their life and bioactivities. As an example, thermophilic microbes playing key roles in aerobic composting require higher temperature, whereas composting earthworms perform better in mesophilic range of temperature.

7. Maturity and Stability Indices:

Compost/vermicompost quality is assessed on the basis of its stability and maturity. Good compost would have the texture of moist loose soil homogeneous and aesthetic. The abundance of physical, chemical and biological changes occurred during aerobic or worm composting. Different parameters proposed to assess the maturity of the compost include the C/N ratios, water soluble carbon, cation ion exchange capacity, CO_2 evaluation, NH_4-N/NO_3-N ratio, organic carbon content, humus content. However, germination index (GI) measuring phototoxicity has been considered as a reliable parameter to quantify compost maturity. A coliform test gives indication of pathogen reduction.

8. On-site treatment of human excreta:

8.1. Composition of human excreta

Human excreta consist of water, microorganisms (including human pathogens), organic and inorganic substances, and nutrients. Most of the nutrients a person consumes end up in feces rendering it as a valuable resource. The quantity and composition of human excreta vary widely from location to location depending upon the food diet, socio-economic factors, climatic condition and water availability. Human excreta are a good source of nutrients. All the nutrients required by the plant are available in the human excreta.

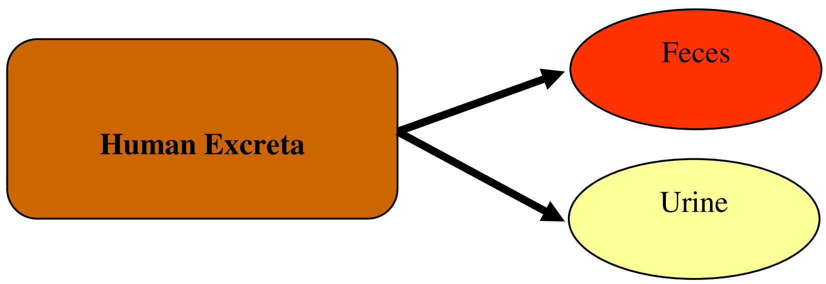


Table 4: Human Excreta Composition (Porto and Steinfeld, 2000)

Processes Parameter	Unit	Urine			Feces		
		Minimum	Maximum	Average	Minimum	Maximum	Average
Volume	L	0.5	2.0	1.2	0.07	0.4	0.18
Weight	g	500	2000	1200	200	400	180
Total Solids	g	20	147	72.4	30	60	44.7
Total Organic Solids	g	65	85	39.1	26	58	44.8
BOD	g	1.8	13.6	7.5	6	18	11.1
COD	g	5.4	30	15.1	19	55	33
Nitrogen	g	3.6	16	10.4	0.25	4.2	2.0
Phosphorous	g	0.5	2.5	1.1	0.1	1.7	0.7
Potassium	g	1.0	4.9	2.3	0.2	1.3	0.7
Calcium	g	0.15	2.2	1.3	0.67	1.4	1.1
Magnesium	g	0.06	0.2	0.13	0.12	0.18	0.15
C/N ratio	-	0.4	1.2	0.8	5	11.3	8.2

8.2. Pathogens in the Human Excreta:

Human excreta contain different types of microorganisms such as protozoa, bacteria, viruses, etc. Many of these microbes are involved in decomposition and cycling of nutrients. However, few types, referred as pathogens, are harmful to human beings as follows….

- Coliform (Total, Fecal)
- Salmonella
- Entric virus
- Helminth Ova

Additionally human feces attract the breeding of insects, which will cause the nuisance and may act as vector of human disease agent. Two types of organisms are particularly resistant to environmental stress: bacteriophages, an indicator, and *Ascaris* eggs, a pathogen. When people ingest pathogens from these media, they become ill. When feces contaminate the environment, the vicious cycle of people contaminating the environment and becoming infected by the contaminated environment continues. Direct health problems are caused when people are exposed to pathogen containing feces via oral or subcutaneous routes. Exposure to pathogens leads to increased incidence and severity of disease, increased risk of dying and malnutrition. Most of the worrisome pathogens are in feces, and less in urine so the treatment of feces and urine is necessary before using it as a fertilizer.

The most efficient way to reduce the contamination of pathogens is by applying the multi barrier system. The first and most important barrier was keeping the excreta away from the people. The barrier approach to sanitation prevents feces from gaining access to the environment: specifically fingers, flies, fields, and fluids, all of which can contaminate food. A number of different methods have been practiced and suggested to reduce pathogens in human waste.

There are three main factors affecting survival of pathogens; pH, moisture and temperature and raising the pH were more effective in killing persistent pathogens than modifying the other two factors.

8.3. Pathogens in Urine:

Urine is usually considered sterile, free of pathogens. Only a few disease organisms are passed through urine. In this regard its reuse has an advantage over or feces. In urine diverting toilets generally the urine are safe, however, cross-contamination from feces to urine may occur. When we store the urine in tank, then the nitrogen in urine converts to ammonia, and the pH rises more than 9 and this elevated pH helps to kill off possible contamination. These conditions will foster die-off of pathogens in urine. If cross contamination does occur, storage of urine for several months should make it safe.

8.4. Processing of Human excreta:

We can process the feces and urine separately or feces and urine combined; the main goal is to return the excreta in the soil. We are producing the human excreta from different type of sanitation system ways the following are the models in practice from where we can produce quality manure.

- Urine Diversion Dehydration (UDD)Toilet
- Pour Flush Toilet with Biogas Plant
- Low Flush Toilet with Solid Liquid Separator

The selection of model depends upon the sociocultural aspects, living standard, priorities, etc. In model we are finally converting the feces in to compost and disposal of wastewater by using the different advanced technologies e.g. constructed wetland, membrane technology, etc.

The urine is generally sterile only the very few chances of pathogens if urine is excreted by an ill person or contaminated with feces. The less processing is required for urine only we have to store the urine minimum for one month and six month is desirable. Only we have to take care during the storage of urine we should keep the urine in airtight container to avoid the nitrogen loss in the form of ammonia. The main processing is required for feces and the level of treatment depends upon the nature of waste.

8.4.1. Urine Diversion Dehydration (UDD) Toilet:

In this type of toilet we are collecting the faces and urine separately and store in separate chamber. After the defecation we cover the waste with bulking material. The bulking material helps in reducing the moisture content and controlling the odor significantly. In the feces processing chamber the feces are desiccated. The desiccation is done by covering the material with different absorbent like sawdust, rice husk and horticulture residue. This bulking material also helps in maintaining the carbon to nitrogen ratio of human waste.

The covering of material like ash and lime helps in raising the pH, and reducing moisture content. The solar radiation also helps in the desiccation process and reduction in the pathogens. In the UDD processing chamber the desiccation and composting process both are going simultaneously but desiccation on the top if we are adding more amount of bulking material compare to quantity of waste. The feces can remove from the processing chamber after the 6 month of storage time from last working day of toilet. We can do the composting of waste out side the processing chamber after the completion of desiccation process. During the desiccation and composting process the main pathogens killing process is the rise of pH and temperature which is controlled by ash/lime and solar radiation. Vermicomposting followed by composting process is desirable to ensure the complete pathogens removal and good quality of end product.

Urine is usually considered sterile, free of pathogens. In UDD toilet we are generating the urine separately so the chance of contamination is low. For proper treatment of urine we only have to store the urine. During the storage the most of the nitrogen will convert in to ammonia. The high amount of ammonia in the container will raise the pH and that will be the main reason to kill the pathogens. When we applying the urine in to the plant the 5-20 times dilution with water is desirable.

In developing countries in the UDD toilet we are also generating the wastewater which is produced during the anal cleaning. Anal cleansing water may be disposed of by local infiltration into the soil.

Bulking Material/ Absorbent:

The main aim of bulking agent/absorbent is to increase the pH and reduce the moisture, content and also arrest the odor from the system. The absorbent also helping in the desiccation process as well helping in the composting process. The absorbent are also play the major role during the reduction of pathogens. The few commonly absorbent used during the composting of human waste……

- Lime
- Ash (Plant litter, dung, and Coal)
- Sawdust
- Agriculture residue
- Horticulture waste
- Rice Husk

For more detailed information on UDDs (designing, operation & maintenance, etc.) please refer to the "Training Manual on Urine-Diversion Dehydration Toilets", which is jointly published by ESF and seecon.

8.4.2. Pour Flush Toilet with Biogas Plant:

In this type of toilet we are generating the excreta rather than feces and urine separately. We are generating the concentrated wastewater from toilet and that will go to the biogas plant for gas production. The solid retention time in the biogas plant generally 60 - 90 days. For efficient working of bio gas plant we have to add the major source of methanogens bacteria by adding the cow dung at different time interval. After the 60 - 90 days retention time what ever the slurry is coming from out of the system that is partially stabilized. For complete stabilization of slurry the composting is cheap and best method. For composting of slurry first we have to reduce the moisture content of slurry by adding the bulking material. Vermicomposting followed by composting process is desirable to ensure the complete pathogens removal and good quality of end product.

For more detailed information on biogas sanitation concepts (designing, operation & maintenance, etc.) please refer to the "Training Manual on Biogas Sanitation", which is jointly published by ESF and seecon.

8.4.3. Low Flush Toilet with Solid Liquid Separator:

In this type of toilet we are collecting the solid and liquid portion separately with the help of solid liquid separator apparatus. The solid chamber has fecal slurry which have moisture content 90±2%. The liquid chamber has urine and wastewater produced which is during the anal cleaning and flushing the feces. The removal of slurry from solid chamber depends upon the storage capacity of chamber it may vary 7 days to 3 month. During the transportation of feces we should take proper precaution because it is partially stabilized. For complete stabilization of slurry the composting is cheap and best method. For composting of slurry first we have to reduce the moisture content of slurry by adding the bulking material. Vermicomposting followed by composting process is desirable to ensure the complete pathogens removal and good quality of end product.

Vermicomposting followed by composting process is desirable to ensure the complete pathogens removal and good quality of end product. The treatment of anal wastewater is possible by different advanced technologies but constructed wetland technology is desirable because it is cheap and best method.

8.5. Major Precautions During the Composting of Human Waste:

- Do the composting in isolated area,
- Add the bulking material to maintain the C/N ratio,
- Maintain the moisture content,
- Use the gloves and mask during the transportation of waste,
- Check the stability of fertilizer before the application.

9. Design of UDD Toilet:

For more detailed information on the designing, operation & maintenance of UDDs please refer to the "Training Manual on Urine-Diversion Dehydration Toilets", which is jointly published by ESF and seecon.

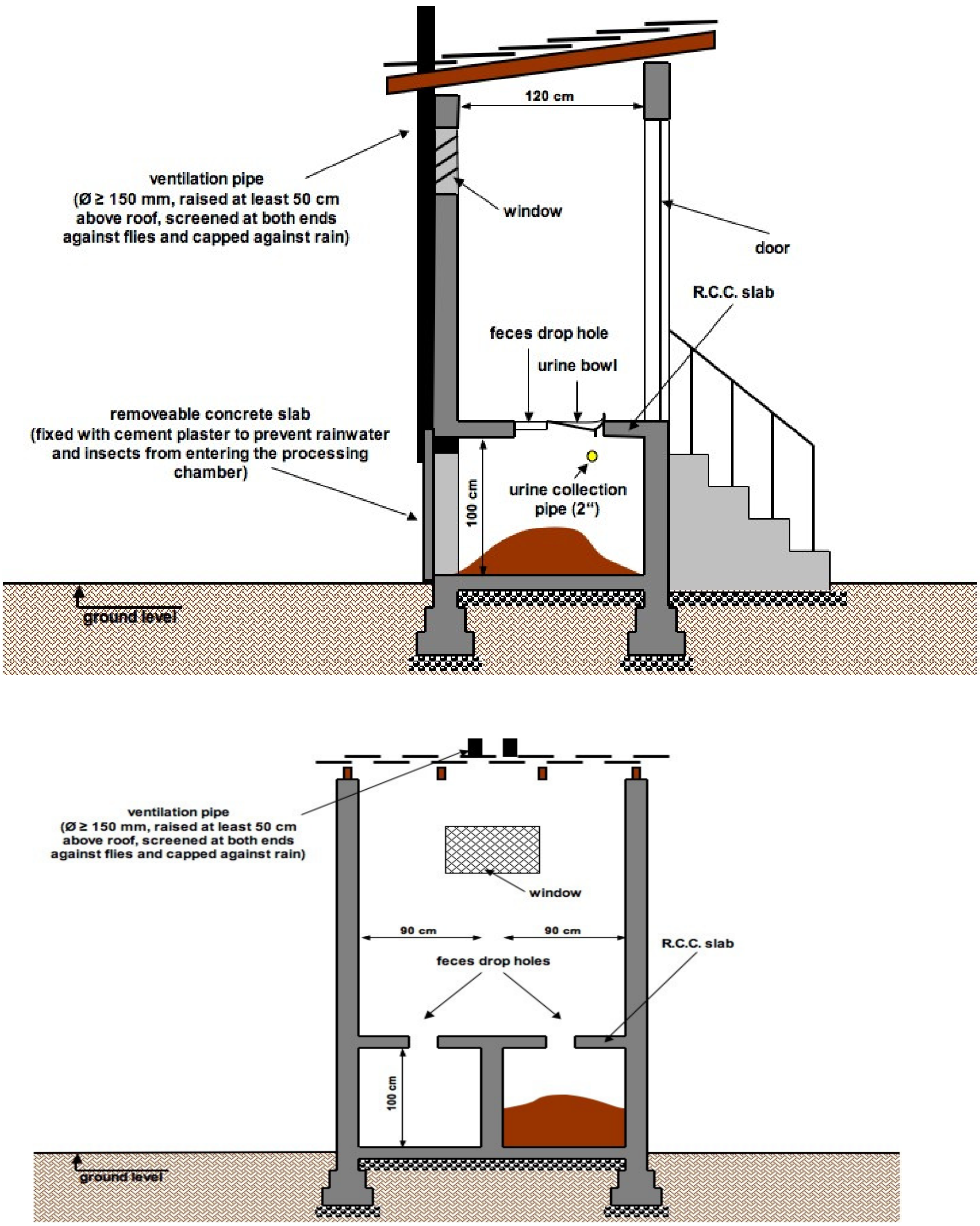


Figure 9: Sketch of Double-Vault UDD-Toilet

10. Design of Waste Processing Plant:

10.1. Design Parameter for Composting Heap:

Width of Heap	: 1 m
Depth of Heap	: 0.75 m
Length of Bin	: 3 m (Not Restricted)
Moisture Content	: 60-70%
Turning of Heap	: Daily (Minimum 3 Days Interval)

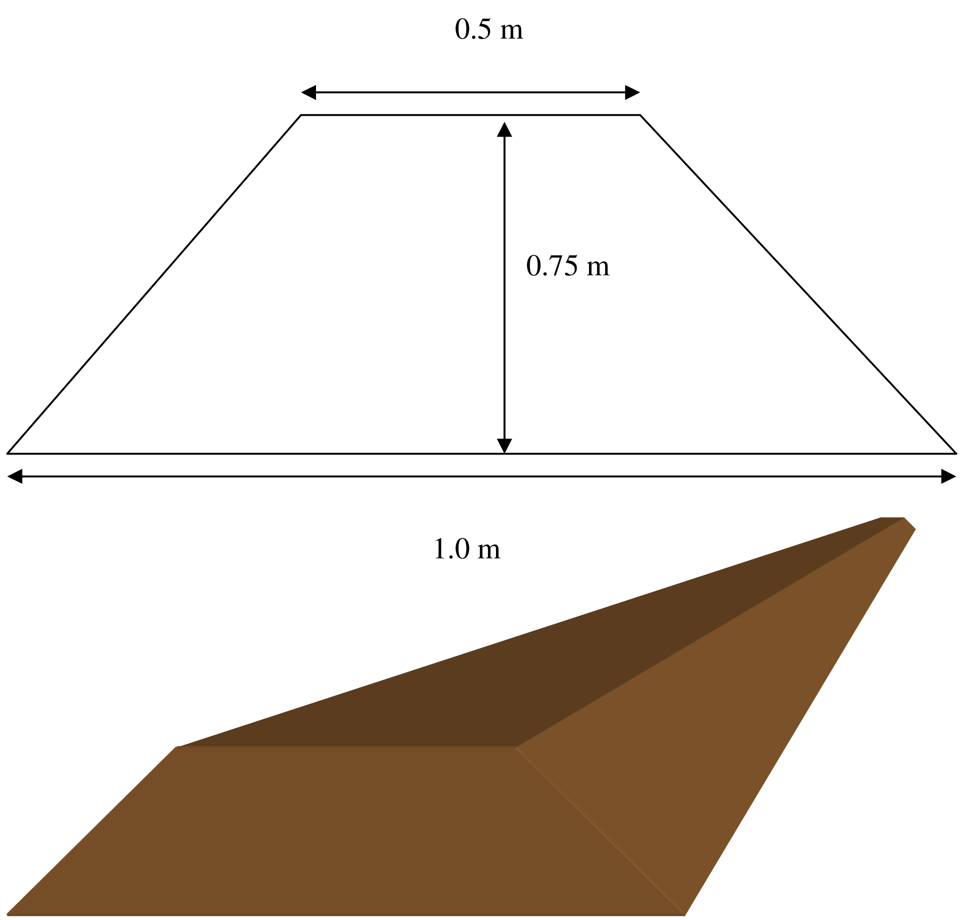
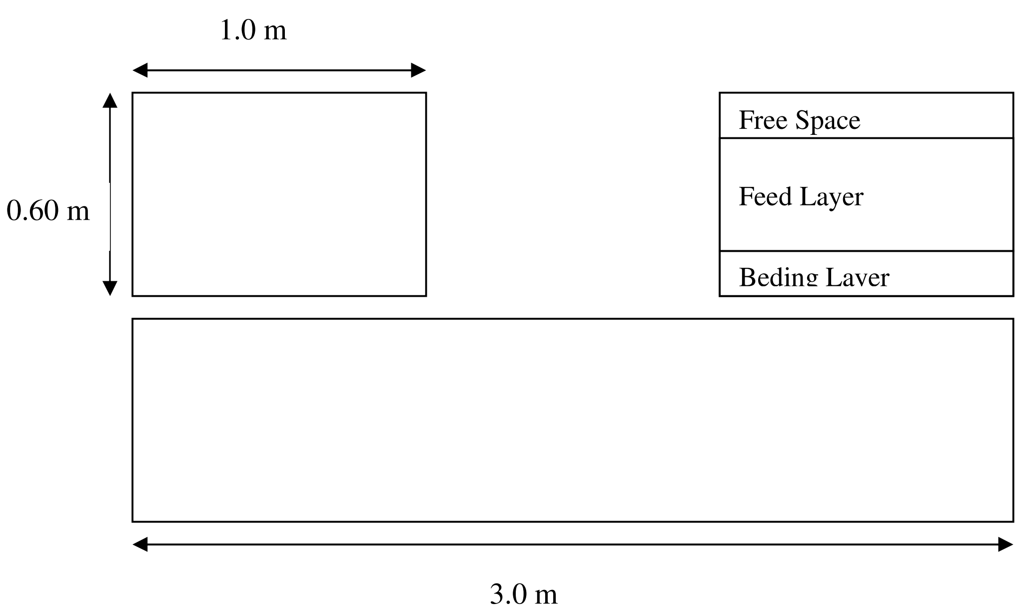


Figure 10: Schematic Diagram for Composting Heap

10.2. Design Parameter Vermicomposting Bin:

Width of Bin	: 1 m
Depth of Bin	: 0.60 m
Bedding Layer/Mulching Layer	: 0.15 m
Feed Layer	: 0.30 m
Free Space	: 0.15 m
Length of Bin	: 3 m
Area of Bin	: 0.60 m^2
Volume of Bin	: 1.8 m^3
Moisture Content	: 70-80% of water holding capacity
Bin Temperature	: 20-30 ^{O}C
Illumination	: Dark
Earthworm Stocking Density	: 2 kg/m^2 (for *Eisenia foetida*)
Quantity of earthworm per m^2	: 1.2 kg
Cast/ Vermicompost removal Interval	: 7 Days



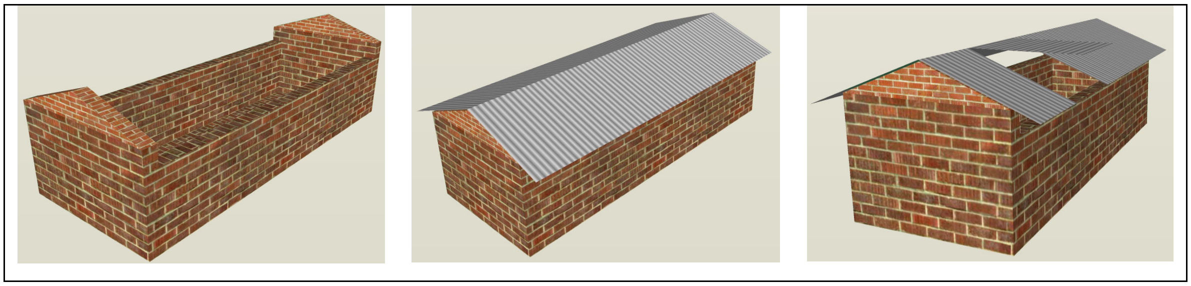


Figure 11: Schematic Diagram for Vermicomposting Bins

11. Conclusion:

The main purpose of manual is to give the information about current sanitation system and their consequences to the environment. The manual also provide the practical and scientific information about problem with chemical fertilizer and their impact on the soil. The manual mainly focuses on composting and vermicomposting process and utilization of that process to produce the good quality organic fertilizer from human excreta. The use organic fertilizer can substantially reduce the soil, water and air pollution. During the handling and transportation of partially treated waste proper precaution is required e.g. wearing of gloves and mask is necessary and washing of hands with soap is mandatory. For detailed information please follow the WHO guidelines for application of fertilizer produced from urine and fecal matter.

Composting is the best way to convert the organic waste in to worth…

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