Agricultural and urban waste compost

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Introduction

- Enormous quantities of wastes are discarded into the environment every day on global scale.
- Many communities and individuals, for some years now, have embraced the practical option for disposing of solid wastes in terms of the "4-R" strategy.
- Materials for discard, under this scheme, are considered in terms of their "re-use", their "recycle", their "recovery," or perhaps whether or not they can be "reduced" in quantity, volume or with respect to their danger to humankind and the environment.

- It is this last category, reduction of waste material, that will be considered here, and the specific example for discussion is the biodegradation of organic matter using the composting process.
- The natural re-cycling of the atoms of biological materials occurs during composting; the process contributes powerfully to the re-cycling and conservation in the soil of carbon, nitrogen, phosphorus, sulfur, potassium, and a variety of naturally important metal atoms.
- Biodegradable material that is so processed offers a product, the humus or compost, that can be returned safely to the earth where it has a nourishing and conserving impact rather than the destructive one, so often typical of much of the waste solids that are frequently dumped onto the land and into landfills.

What is Composting?

- Composting is the controlled microbial bio-oxidative process involving biodegradable organic matter, conducted under controlled environmental conditions.
- The oxidation produces a transient thermophilic stage which is followed by a period of cooling of the now degrading organic matter.
- The material is held at ambient temperatures for maturation purposes which results in a stable, volume reduced, hygienic, humus-like material—the compost—that has retained mineral elements beneficial to soil and plants.

- Compost is the product of the controlled microbial degradation of heterogeneous organic matter into a safe and beneficial humus-like material.
- Emphasizing a "controlled" process distinguishes composting from "uncontrolled" rotting or the simple putrefaction of organic matter.
- Furthermore, bio-oxidative metabolism of the microorganisms involved ensures that the bulk of the biodegradable carbonaceous matter will be dissimilated completely to CO_2 and water.
- Other components or organic matter, such as nitrogen and sulfur, will be assimilated into microbial cell mass, only to be liberated again after the cells die and degrade.

- The oxidative metabolism of microorganisms is exothermic, and the heat produced is sufficient to increase the temperature of organic matter to between 60 and 75°C over a period of up to 10 days.
- This so-called "thermophilic stage" offers a selfsanitizing mechanism by which pathogens, seeds and heat-labile microbial and plant toxins (phytotoxins) will be destroyed.
- Not all organic matter will be degraded completely. For example, lignin in plant material will be modified and become part of the final stable product. These modification processes are slow and occur during the maturation stage.
- The final humus-like material, the compost, is a dark, crumbly, earthy material usually containing less than 2% (w/w) each of nitrogen, potassium, and phosphorus (N:P:K). When applied to soil, these minerals are available to plants while at the same time the compost offers improved soil structuring characteristics (conditioning).

Compostable Materials

- In theory any naturally synthesized material can be composted. However, some materials can be stabilized much faster than others.
- Soluble plant exudates and sap will be bio-oxidized much more rapidly than lignin and ligno-cellulosic materials. These latter components of vegetable matter will be modified by the composting process and will thus contribute to the texture and plant-nutritive value of the final product.
- Crop residues are compostable, but although high in carbon they are deficient in nitrogen.
- Animal wastes (faeces and urine) offer rich sources of nitrogen but are often low in carbon content, especially in the case of omnivorous animals. Herbivores, being incapable of digesting all of their cellulose intake, will excrete compostable carbon in addition to the above mentioned nitrogenous material

- Food industries processing agricultural produce generate compostable wastes, although possibly the most difficult to process are solid wastes and waste waters from vegetable oil extraction presses.
- Treatment of solid wastes arising from slaughterhouses and meat-packing facilities also represent a special problem since this waste material is almost devoid of carbohydrate material, and yet is rich in fat and protein.
- With these wastes, every care is needed to facilitate controlled biooxidation and to avoid anaerobic putrefaction

- To be compostable, municipal solid wastes require processing such that the biodegradable material is separated from all other solids (glass, metal, plastic, and other non-biodegradable substances) likely to be present in such wastes.
- Size reduction is generally used to maximize the surface area available to attack by microorganisms.
- This also assists in obtaining a uniform particle size in the final compost. There is always the likelihood that classified and pulverized compostable municipal solid wastes may be contaminated with hazardous materials (for example, pesticide residues and traces of heavy metals).

- This is of concern to the relevant authorities, since compost could be a route whereby toxic materials are returned to the environment.
- Municipal sewage sludge is also compostable. High in nitrogen as it is, it requires augmentation with carbon and adsorbtion onto a carrier material (e.g. wood chips or bark) to facilitate free movement of air through the sludge.

Process Considerations

- Composting offers a waste management system that reduces the volume of wastes, stabilizes otherwise putrefactive organic substances and recovers some of the nutrient value of biodegradable solids.
- Three broad stages of the process can be identified.
- (i) preparation of the waste solids;
- (ii) bio-oxidative stabilization of the organic material by the composting ecosystem;
- (iii) preparation of the matured compost for commercial sale as a biofertilizer.

- The preparation of organic solids for composting attempts to ensure that optimal conditions exist for the bio-oxidative reactions that are required for organic matter stabilization.
- Surface area of the compostable solids must be maximized to allow oxygen availability and enable rapid microbial action. Mechanical shredding or pulverizing of agricultural residues and of biodegradable municipal wastes is practiced.
- Other wastes may not need this preparatory treatment. For example, wastes from meatworks and meat-packing houses are usually composed of paunch contents, stock-pen wastes (faecal), meat, skin, and hide scraps, and sludge from primary and sometimes secondary biological treatment systems.
- Mechanical size reduction of these materials is usually not required.

- Biosolids (sludges) arising from sewage treatment plants pose a different problem.
- Biosolids are characterized by their small particle size, and because of their density and water content they tend to pack down. This impedes ventilation. Consequently a "bulking agent" is required.
- **Bulking agents** are non-nutritive additives that increase the **bulk** (volume or weight) of a food or other material without affecting its taste and keeping its utility and functionality intact
- Mixing the biosolids with a bulking agent leads to the adsorption of the particles onto the surfaces of the latter. The available area of substrates exposed to biooxidizing microorganisms is thus increased.
- Large chips of wood or bark (from 3 to 5cm long and 0.5 by 3cm in cross-section) facilitate air-flow through the pile. However, finer cuts of wood such as wood-shavings and coarse sawdust allows better access to the carbonaceous material by actinomycetes, bacteria and fungi.

- Bulking agents and biosolids are mixed in a ratio of 1 part bulking agent to 2 parts compostable waste. Figure 2 illustrates the adsorption of a fine-particle waste on the bulking agent and the spaces between fragments of bulking agent to facilitate ventilation.
- Chimney fly ash has also been added to bulking agents as an inert extension to the agent.

- The role of the bulking agent is to: increase the surface areas available for bio-oxidation, especially when the organic substrate to be stabilized is composed of particularly fine particles;
- Assist ventilation of the mass to facilitate bio-oxidation. About 30% of the pile volume should be air spaces. Good ventilation will also purge metabolic CO_2 ;
- Produce a dark, loam colored final product, especially from using wood or bark chips;
- Ensure that moisture is available for the metabolic processes;
- Maintain the structural integrity of the windrow and static pile.

- Thus the bulking agent can be regarded as a regulator of the bio-oxidative process rate, and also assists in balancing the ratios of biodegradable organic matter, moisture, and available oxygen.
- Use of bulking agents is particularly important in the stabilization of secondary (biological) treatment sludges and other wet compostables.
- Dry-material wastes (e.g. agricultural residues) may not require a bulking agent.
- The final stage of the process is to prepare the material for commercial sale.
- At the end of the maturation phase the bulking agent is recovered by screening. It can be reused. The mature product may be milled to ensure uniformity of particle size and packed into bags (usually plastic) for commercial sales. Bulk quantities may also be offered to horticultural interests.

System Configuration

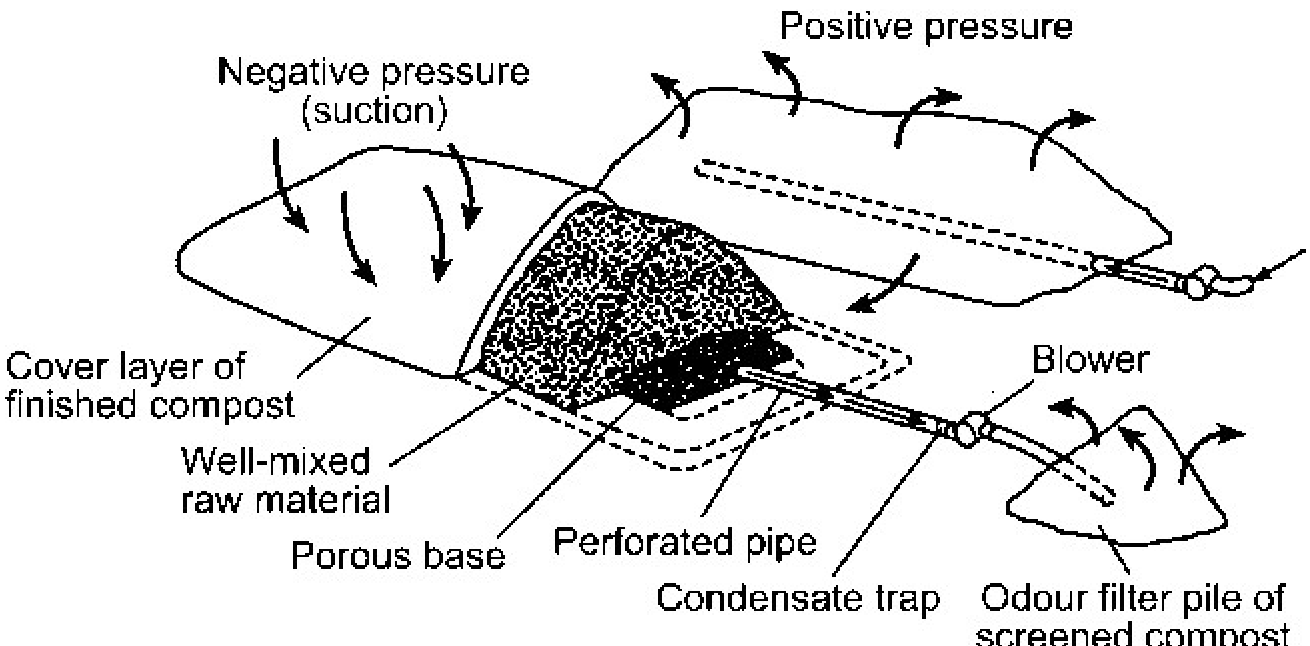
- There are many configurations of the composting systems and a number of "classifications" are used to describe them.
- For example, "static", "agitated", "open", "closed", "unconfined" and "confined" are terms used to describe the various configurations.
- A number of these systems are described and the terms briefly explained.

Static systems

- Static systems are those that heap the mass of waste and bulking agent into a long pile or windrow.
- However, the windrow may or may not strictly be static because the entire mass may be re-mixed (or turned) twice a week to ensure a renewal of the oxygen supply for bio-oxidative reactions, or it may be ventilated artificially by running perforated air-pipes longitudinally along the base of the pile.
- This system, using forced aeration of the static pile, was developed by the US Department of Agricultural Research Station in Beltsville, Maryland, and has been referred to as the ARS process or Beltsville process

Static System for composting

- These static systems are batch operations, although in large operations the pile may be extended and thus allowed to lengthen.
- The mature compost is removed from the oldest end while new material is continually added at the other end of the pile. Piles will have a trapezoidal longitudinal shape, and a triangular cross-section where the base width is approximately twice the height.
- An optimum base width is 3 to 4m.
- Windrows and static aerated piles are regarded as "open" or "unconfined" systems.
- For industrial scale operations considerable land area is required especially in the case of windrow processing where the material is to be turned regularly.


Positive pressure
Negative pressure
(suction)
Cover layer of
finished compost
Well-mixed
raw material
Porous base
Perforated pipe
Condensate trap
Blower
Odour filter pile of
screened compost

Windrow

Passive Aerated Windrows:

- Natural convection of air within a static pile brought about by temperature gradients is the basis of the Passive Aerated Windrow (PAW) system.
- A series of rows of plastic pipes with holes drilled in the top are arranged on a bed of mature compost or peat and the pile built on top of them.
- The pipe ends protrude outside the pile, allowing air access into them. As was the case with other static piles, the heap is covered in an envelope of mature compost.
- Heat generated by bio-oxidation heats the middle and upper regions of the pile, warming air trapped in the air spaces. As this warm air rises and circulates outwards (but within the pile), it is replaced by cool air drawn from the bottom of the heap through the holes in the pipes.

- While bio-oxidation proceeds and generates heat, ventilation is sustained at rates that vary with the amount of convection present (i.e. with heat generated).
- This system has been applied successfully to the composting of proteinaceous wastes where there is the likelihood of ammonia and amine odors developing.
- These gases are trapped in the compost and turning (as is the case for the traditional windrow) is undesirable.
- Forced stabilization of the pile may cause loss of ammonia.
- In this PAW system, any ammonia escaping into the mature compost envelope covering the pile may be stabilized to nitrate by bacterial nitrification. Thus, the N content would be retained within the pile.

Agitated, Closed, Confined, In-vessel:

- Agitated, Closed, Confined, In-vessel are terms used to describe batch or continuous composting that can be achieved using a closed, large vessel.
- Furthermore, these configurations when operated continuously can be regarded as either plug-flow or fully mixed systems.
- The Danish "Dan" system provides an example of a continuous plug-flow system. Materials to be composted are fed into the top of a "biostabilizer", which is a 3 to 4m diameter downward-slanting cylindrical chamber up to 30m long rotating at about 1rpm.
- Forced air ventilation is provided and metabolic gases, steam, and unused air are extracted by fans.

- Temperatures can reach 55 to 65˚C within the tumbling material, and the bottom exiting hot mixture is screened and conveyed to maturation beds.
- Retention times in the biostabilizer vary from 3 to 5 days.
- Alternative plug-flow systems use a hydraulic ram to slowly push the composting material along a closed, ventilated, tubular reactor.
- In contrast to these plug-flow composters, there are the fully mixed systems in which material to be composted is fed into a large vessel and mixed by an array of vertical augers (vertical mixed reactor) or mixed by an inclined conveyor belt (horizontal mixed reactor).
- These systems are thoroughly ventilated to ensure that bio-oxidative reactions occur at optimal rates.

- Both the plug-flow and fully mixed configurations are completely enclosed and not subject to variations in weather conditions, as is the case with windrows.
- Closed composting systems are experiencing increasing interest because the compactness of the operational units and diminished land requirements.
- Furthermore, better control of processing conditions is possible, especially feed rates, temperatures, aeration, and odor control.
- Retention times in the reactors may vary from a few days to 2 weeks. A further 3 month period for curing can be conducted off-site if necessary

- Large scale vermicomposting is carried out in vessels raised off the ground (to facilitate controlled drainage) with the material to be stabilized and the bulking agent loaded to a depth of about 1 meter.
- At ambient temperatures earthworms bring about aeration and mixing of the material, and its bio-oxidation and stabilization over a period of about 30 days

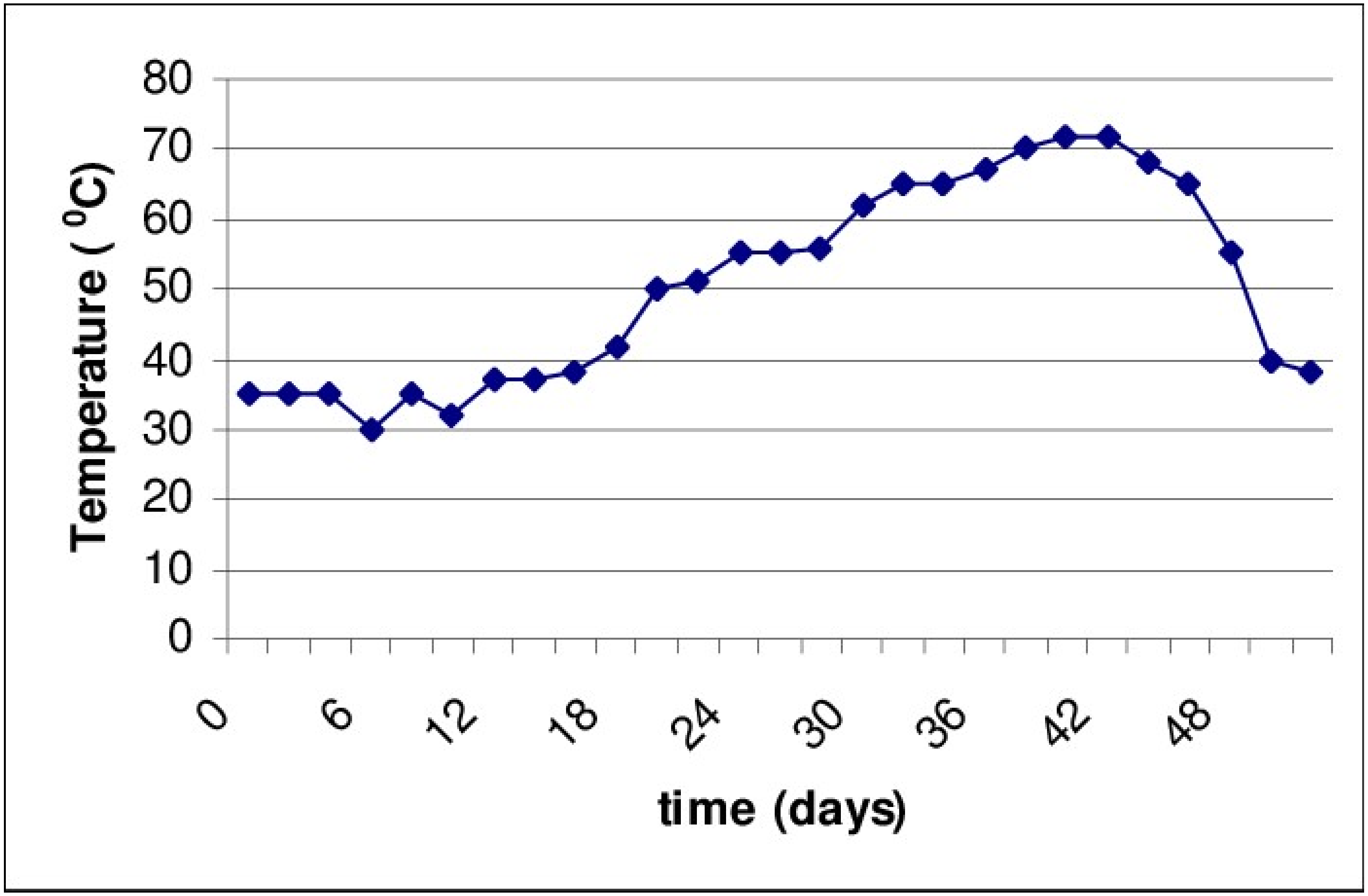
Operating Conditions

- The traditional composting process applies biological principles to ensure that organic matter is fully recognized in the minimum time.
- Thus, factors affecting the functioning of the biological populations must be understood and recognized as being essential to successful composting operations, i.e. the production of a high quality product in minimal time.
- These influential factors viz., temperature, oxygen, moisture, substrate and pH, are discussed below

Temperature

- The most important physical factor affecting rates of biochemical reactions is temperature.
- Throughout operations, no external heat is added to the composting mass because there is sufficient metabolic heat generated by exothermic reactions (under appropriately controlled operations) to raise the mean temperature to between 50˚ C and 70˚ C in the first few days, and to hold temperatures between 50˚ and 60˚ C for the next twenty or more days.
- After this time, temperatures steadily return to ambient over a further 20 to 25 days.
- Although metabolic heat may be sufficient to raise temperatures to 78˚ or even 80˚ C, it is realized that if these temperatures last too long the activity of the microbial populations is inhibited.

- So very high temperatures (above 70˚ C) for long periods should be avoided.
- Because of the nature of the pile, heat transfer within it is poor and localized hot-spots are possible.
- Cooling the overheating mixture is achieved in windrow systems by turning the mass at regular intervals or by forced air ventilation in the case of static piles.
- Likewise in plug-flow and fully mixed systems, forced air ventilation is used as the coolant.
- Ventilation is never continuous, and appropriately selected upper and lower thermistor set-points ensure temperature control can be achieved through on-or-off control of air flow.



Temperature profile during composting

Pile Aeration

- Ongoing bio-oxidative activity is achieved by supplying the active microbial population with oxygen.
- Aerobic respiration is encouraged and fully biodegradable organic substances are stabilized as carbon dioxide and water.
- Non-fully biodegradable substrates such as lignin and ligno-cellulosics have their molecular structures modified only and are not biodegraded completely.
- In windrow systems, aeration is achieved by turning the pile two or three times a day during the early period when temperatures are rapidly increasing towards a maximum.
- This is particularly necessary for highly nitrogenous wastes to off-set the potential for putrefaction occurring, and the concomitant formation of offensive odors.

- Once themophilic temperatures are achieved, the windrows are turned on a daily basis for the next 25 to 30 days.
- Industrial scale operations demand specialized heavy equipment for turning windrows with rates ranging between 2000 and $3000m^3\ h^{-1}$ being used.

- Aeration of static forced-air piles can be achieved using either air-blowing or vacuum systems (Figure 5).
- Because air is being forced through the pile, these static piles are never turned. Using forced-air aeration it is possible to construct very long industrial scale piles with an optimum base width of 3 to 4m.
- In the Beltsville method perforated parallel plastic pipes 10 to 15cm in diameter run the length of the pile (Figure 3).
- They are mounted in a layer of bulking agent (wood-chips) or screened mature compost and they terminate approximately 2m from the end of the pile.

- These pipes, connected by a non-perforated manifold, ensure aeration of the entire pile.
- The manifold is connected to an air pump that either sucks air through the pile and delivers both it and metabolic gases into a gas-filter of mature screened compost (for odor control), or alternatively pushes air out via the perforated pipes and through the pile.
- Odor control is not as easy under an air blowing configuration. However, there is evidence that blowing air through the static pile allows better temperature and moisture control.
- In closed, fully mixed systems, forced aeration is used and monitoring of the exhaust gases ensures adequate supply of oxygen at all times.

- During bio-oxidation, the air passing through the compostable organic material will become depleted in oxygen and enriched with CO2 .
- Analysis of exhaust gases from static piles indicates that 5% oxygen in the gas phase may be the limiting value. Below this amount the pile may become anaerobic, with odorous compounds generated.
- The aeration optimum during the thermophilic stage, when bio-oxidative reactions are maximal, is considered to be from 0.6 to 1.8m3 air per d -1 kg -1 of volatile solids.
- However, it should be noted that the rate at which air is forced through the pile also impacts on both the temperature (it has a cooling effect) and the moisture content (an evaporative effect). Thus there can be a complex interaction between these three variables.

Moisture

- The amount of moisture in the material to be composted will vary according to the nature of that material, and so it is only after mixing with bulking agent that the moisture content of the aggregate is measured.
- Adjustment can be made by adding water or more bulking agent, but ideally the initial moisture should be in the range of from 30 to 60% (w/w).
- Because of difficulties in changing the composition of forced aeration and PAW piles as well as plug flow mixtures once composting has started, every effort should be made to have the moisture at its optimal range before bio-oxidation commences.

- Microbial action requires water and it is in the film of moisture on the bulking agent and at the water-air interface that the bio-oxidative reactions occur.
- Too much water excludes air from the free-air space, slowing down the transport of oxygen to the microbial cell and consequently limiting metabolic activity and microbial growth.
- Furthermore, the nature of the inert bulking material influences the amount of water present because of its water absorbing characteristics.
- For example, sandy soils will seem very wet at 50% (w/w) water whereas a peat will seem dry after adding the same amount of water.

Substrate

- The substrate to be oxidized can be categorized according to its carbon to nitrogen (C:N) ratio. This ratio is probably the next most influential factor for successful composting after temperature.
- Substrate is used by the microbial population for two purposes; (a) to synthesize new cells and (b) to produce energy as ATP to drive the biosynthetic processes.
- Although the microbial cell itself is approximately 50% carbon and 5% nitrogenous material (i.e. it has a C:N ratio of between 9:1 and 12:1), the requirement of carbon for energy production and its dissimilation to CO_2 means that considerably more carbon is required (usually between 25:1 and 35:1) than is reflected in the C:N ratio of cellular components.
- If the C:N ratio exceeds 35:1 then the system is nitrogen limiting and microorganisms require greater time to metabolize the excess carbon.

- Consequently the process time is extended. If the ratio falls below 25:1 (i.e. if there is in proportion more nitrogenous material available) then odorous compounds such as ammonia and amines will be formed.
- This represents a loss of nitrogen that otherwise would remain in the compost.
- Table 1 illustrates some approximate values of the C:N ratio for biodegradable wastes processed commercially.

- Carbon to nitrogen ratios of crop residues and other organic materials

Material	C:N Ratio
rye straw	82:1
wheat straw	80:1
oat straw	70:1
corn stover	57:1
rye cover crop (anthesis)	37:1
pea straw	29:1
rye cover crop (vegetative)	26:1
mature alfalfa hay	25:1

Ideal Microbial Diet	24:1
rotted barnyard manure	20:1
legume hay	17:1
beef manure	17:1
young alfalfa hay	13:1
hairy vetch cover crop	11:1
soil microbes (average)	8:1

- Carbon to nitrogen ratios can be poised to the optimal value (25:1) by mixing the substrate to be composted with other biodegradable materials prior to commencement of composting operations.
- For example, sewage wastes relatively rich in nitrogen can be augmented successfully with woodchips or vegetable processing wastes which are low in nitrogen.

Compost Mixture pH

- All biological systems function best over a pH range of approximately 5.5 and 8.0 and the microorganisms found in the compost mixture are no exception to this.
- Bacterial populations during the first few days make heavy demands on oxygen and are responsible for oxygen deficits in the pile. If the respiratory processes are replaced by fermentation of the carbohydrate substrates, then volatile fatty acids (such as acetic acid) may accumulate. In such an event the pH will decrease to approximately 4.5.
- At this degree of acidity bacterial growth is likely to be replaced by fungal activity, providing adequate oxygen is available. At low pH, divalent metal ions such as Ca and Mg, (which are used as microbial cell nutrients), and heavy metal ions such as Mn, Co, and Fe (used by microorganisms in trace amounts), as well as Al, may be leached from the compost.
- Increased aeration and the addition of lime are used to reverse sharply decreasing pH values. The addition of too much lime, however, will make the mixture alkaline.

- Proteinaceous food wastes, fresh animal manures, and grass clippings may lead to the formation of ammonia, which will increase the pH value.
- Above pH 8.5, ammonia is lost to the composting mixture by volatilization. Compost plant operators are aware of the possibility that during the early thermophilic stages of the processes (when oxygen limitations are likely), deamination reactions at elevated temperatures can release copious quantities of both ammonia and amines.
- These vapors represent a hazard to both operators and the environment.

- Additionally, these losses mean less nitrogen is available from the matured compost for plant growth.
- To control the tendency for composting mixtures to become alkaline, mixing in powdered sulfur, peat, and/or acidic paper mill pulp sludges have been used.
- The pH of the mature compost should be between 7 and 8. Figure 7 depicts the changes in pH during the processing of a static aerated pile.

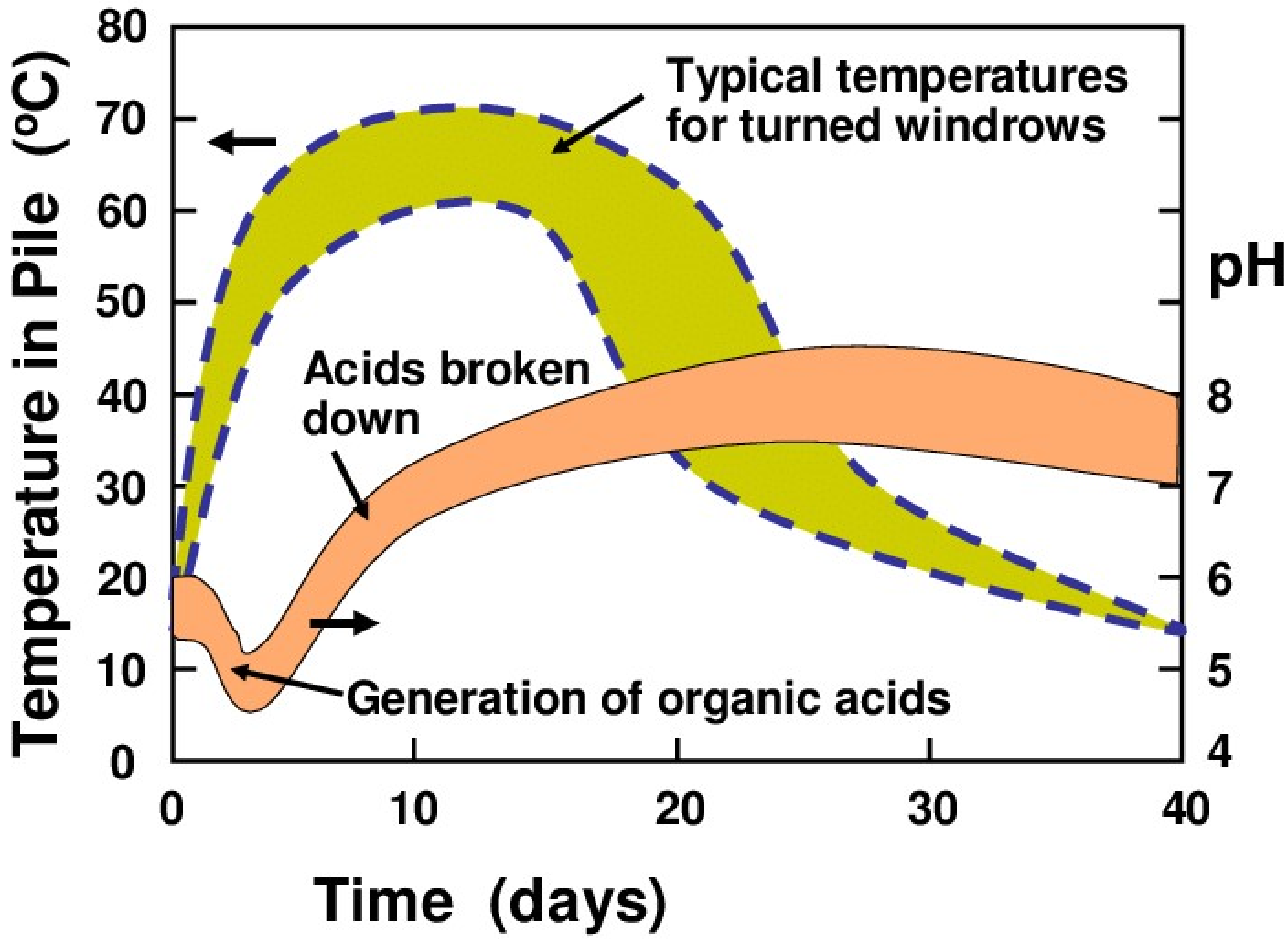


Figure 7. Changes in pH during composting (Static Pile).

Odor and Its Control

- The odors arising from poorly managed composting operations can be objectionable, and the extent of odor emissions from commercial scale operations has forced plant closures.
- At least 179 different chemical compounds have been identified in compost emissions, including alcohols, aldehydes, amines, ammonia, volatile fatty acids (such as acetic, butyric, and valeric), esters of these fatty acids, ketones, sulfides, thiols, and terpenes. "Compost odor," then, is a mixture of many or all of these substances, and their generation depends on the nature of the material being processed and the conditions existing during processing.
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- Under anaerobic conditions, V.F.A., mono and diamines may also be produced.
- These too are very odorous, and again represent a loss of nitrogen from the compost.
- In situations where the addition of extra carbonaceous substrate is not available to supplement excess nitrogenous materials and allow optimal C:N ratios, a different treatment process—namely anaerobic digestion—should be considered
- In turned windrows regular disturbance of the pile quickly dissipates these odors while in aerated piles and closed systems, the odors can be passed through an earthen filter (also called biofiltration). Biofiltration depends on microorganisms that are naturally present in the filter material to oxidize odorous compounds to less noticeable molecules and to adsorb them on the filter particles.

- Biofilters ("soil filters," see,*)* have become popular in recent years because they offer a cheap and effective odor control option in small to medium sized operations.
- Odorous gases are passed through a column of earth, lignite, coke, mature compost, sawdust, woodchips, or fine bark. Process mechanisms operating are presumed to be adsorption, absorption, and biooxidation by microbial populations inhabiting the moisture film found on the packing medium particles.
- Oxidative metabolism leads to the mineralization of the organic odor components (i.e. the production of CO2, water, mineral salts and more microbial cells).

- Odor compounds (ammonia, amines, volatile fatty acids and sulfur compounds such as hydrogen sulfide, sulfur dioxide and mercaptans) have been removed successfully using biofilters.
- The biofilters need to be kept uniformly moist at all times to facilitate microbial metabolism and free of channels which otherwise will allow odors to escape.
- Flies are a problem often associated with odor production. The extensive area of windrows and aerated piles, with their potential to release odorous compounds, attract a variety of flying insects .
- A covering "blanket" of mature compost up to 150mm thick over the windrow is usually successful in preventing insect colonization. Such a covering for a regularly turned windrow is not practicable unless the process is mechanized using synthetic covers.
- Commercially available covers for use in large scale operations allow rapid covering and uncovering of windrows

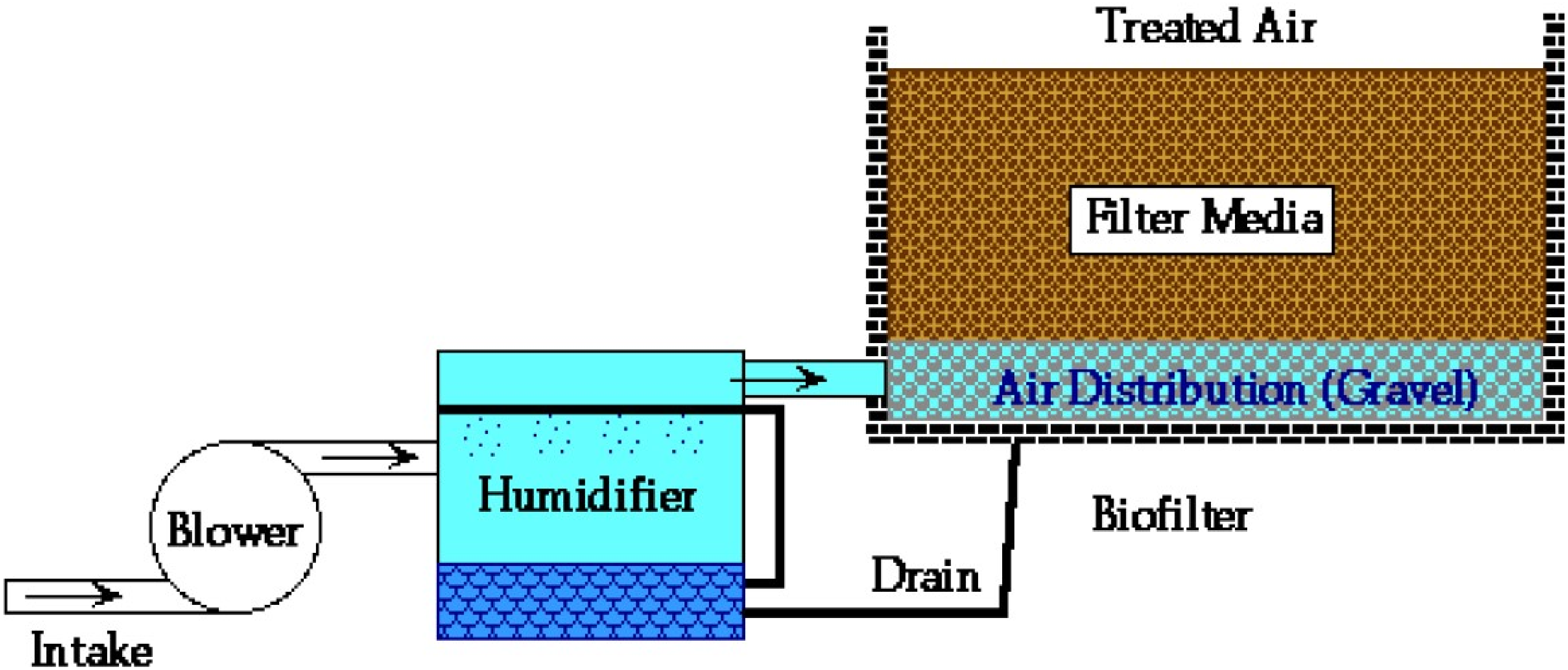


Figure 8. Biofilter assembly for compost odor mitigation.

Figure 9. Commercial compost covers which can be deployed quickly should allow exchange of air and metabolic gases and exclude rainwater.

Process Additives

- These are some materials which when added to the compost mixture enhances the rate of microbial bio-oxidation, indicating that there is a deficiency of these certain nutrients in the compost material.
- Sometimes the additives enhances the cost of the process, but gives only a marginal economic benefit.
- However, they help in achieving the initial C:N ratio is in the required range (approximately 30:1).
- Carbonaceous additives:

  These are useful for compost substrates having more nitrogen content than carbon. Examples of these additives are: straw, pea weed, starchy material, or leaf litter),
- Nitrogenous additives:
- These are useful for compost substrates having more carbon content than nitrogen . Example of these additives is urea, other fertilizers rich in nitrogen.
- In addition to nitrogen Agricultural fertilizers also provide other nutitive elements such potassium and phosphorus to overcome deficiencies in these elements.

- The agricultural fertilizers also act as the source of trace metals like Zn, Co, Cu, Mn, and Mo and macro-nutrient metal ions (e.g., Mg and Ca).
- **Microbial starter cultures:**

  Microbial starter cultures are also available to accelerate the bio-oxidative process. However, in they are generally too expensive for large-scale operations.
- As an alternaitve moist, mature compost, can be added during start-up mixing of the wastes and other components, and it has been shown to make the composting process faster.
- Shredded paper and paper products have been added to biowastes as alternatives to bulking agents and to help adjust the C:N ratio. Ammonia losses can be reduced using paper as a carbon supplement

The Mature Compost

- A mature compost (i.e. the biodegraded product of organic material that has been processed by controlled biological bio-oxidation under aerobic and thermophilic conditions) is expected to have characteristics that are consistent and universally acceptable.
- It should be consistent in colour, texture, and smell; contain plant nutrients; be devoid of materials that will putrefy further; be free of plant and animal toxins, including heavy metals and biocide residues; be free also of unwanted seeds and insect larvae as well as human, animal, and plant pathogenic microorganisms.
- So, there is a need for industry quality standards, and even for national and international standards to govern the certification of a compost product exhibiting minimum acceptable quality.

- Other major criteria that are used to define quality include organic matter content, carbon to nitrogen ration (C:N near 10 for the finished product), bulk density, moisture to dry-matter content, pH value, residual odor, plant available nutrients, age at time of packaging or delivery, major feedstock used (i.e. the component present initially in excess of 10% of total), electrical conductivity, and tolerance of plants to the product.
- Manufacturers' associations are moving closer to agreement concerning appropriate guideline values for these criteria

Nitrogen Conservation in relation to C/N Ratio

Initial C/N Ratio	Final % of Nitrogen (N) (dry weight basis)	% N loss
20	1.44	38.8
20.5	1.04	48.1
22	1.63	14.8
30	1.21	0.5
35	1.32	0.5
76	0.86	-

Temperature and Time of Exposure Needed for Destruction of some Common Parasites and Pathogens.

Organisms	Time and Temperature for destruction
S. typhosa	No growth beyond 46˚C, death in 30 minutes at 55-60˚C and 20 minutes at 60˚C,destroyed in a short time in compost environment.
Salmonella sp.	In 1 hour at 55˚C and in 15-20 minutes at 60˚C
Shigella sp.	In 1 hour at 55˚C .
E. Coli	In 1 hour at 55˚C and in 15-20 minutes at 60˚C
E. histolytica cysts	In few minutes at 45˚C and in a few seconds at 55˚C.
Taenia saginata	In a few minutes at 55˚C.
Trichinella spiralis larvae	Quickly killed at 55˚C, instantly at 60˚C.

Organisms	Time and Temperature for destruction
Br. abortus or Br. suis	In 3 minutes at 62-63˚C and in 1 hour at 55˚C
Micrococcus pyogenes var. *aureus*	In 10 minutes at 54˚C
Streptococcus pyogenes	In 10 minutes at 54˚C
Mycobactercum tuberculosis var. hominis	In 15-20 minutes at 66˚C or after momentary heating at 67˚C.
Corynebacterium diptheriae	In 45 minutes at 55˚C.
Necator americanus	In 50 minutes at 45˚C .
A. lumbricoides eggs	In 1 hour at 50˚C.

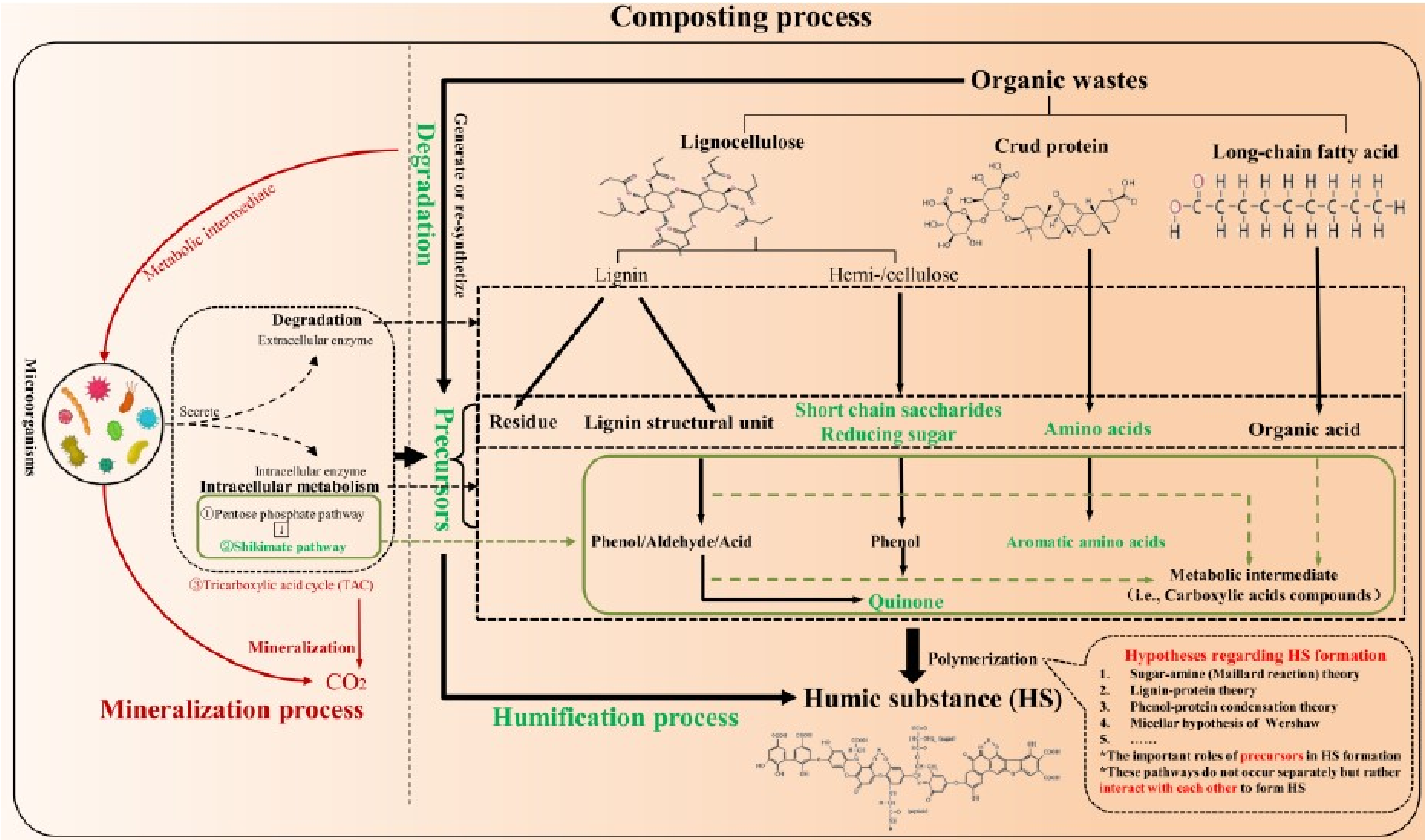


Fig: Diagram of composting process mechanism. Red continuous arrows indicate mineralization process (the emission of carbon dioxide, CO_2), black continuous arrows indicate humification process (the formation of humic substance)

Ecology of Compost Systems: Microbial Populations

Microflora /Microfauna	Organisms	Mesophilic Stage	Thermophilic Stage
Microflora	Bacteria	10^8 cells g^{-1} *Pseudomonas, Bacillus, Flavobacterium, Clostridium*	10^9 cells g^{-1} *Bacillus* spp., *Thermus thermophilus, Hydrogenobacter* spp
	Actinomycetes	10^4 cells g^{-1} *Streptomyces*	10^8 cells g^{-1} *Streptomyces, Micropolyspora, Thermoactinomyces, Thermomonospora*
	Fungi	10^6 fungi g^{-1} *Alternaria, Cladosporium, Aspergillus, Mucor, Humicola, Penicillium*	10^7 fungi g^{-1} *Aspergillus, Mucor, Chaetomium, Humicola, Absidia, Sporotrichum, Torula* (yeast), *Thermoascus*
Microfauna	Protozoa		
Macroflora	Fungi (Mushrooms & Toadstools)		
Macrofauna	Mites, Ants, Termites, Spring tails, Millipedes, Centipedes, Earthworms		

Some Bacteria capable of utilizing various components of organic matter

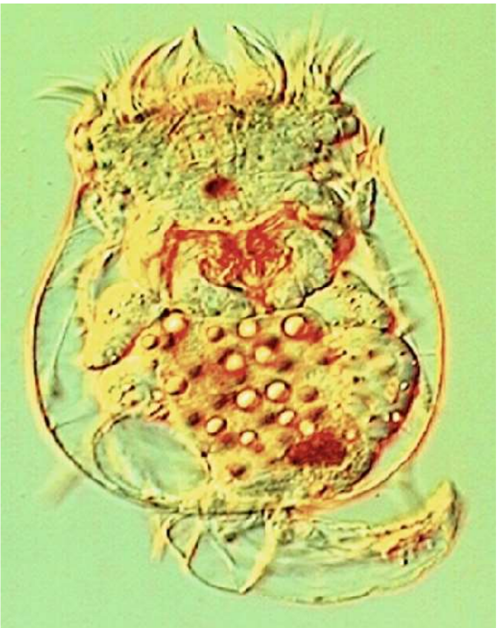
Substance	Bacteria
Cellulose	*Achormobacter, Bacillus cellulomonas,cellvibrio,clostridium, cytophaga,pseudomonas,sporocytophaga, vibrio*
Hemi-cellulose	*Bacillus, achromobacter,cellulose pseudomonas, cytophaga, sporocytophaga,Lactobacillus, Vibrio.*
Starch	*Achromobacter, Bacillus, Chromobacterium Clostridium,Cytophaga,Rhizopus Flavobacterium,Micrococcus, Pseudomonas,Sarcina, Serratia*
Hydrocarbons and Pesticides	*Methanobacterium, Methanobacillus, Methanosarcina, Methanococcus, Pseudomonas*
Proteins	*Pseudomonas, Corynebacterium Mycobacterium, Bacillus, Vibrio*

SUMMARY OF COMPOSTING

- Compost Biota
    - Fauna
    - Protozoa
    - Decomposer microorganisms
        - Bacteria
        - Actinomycetes
        - Fungi

- **Fauna**
  - Important in the beginning of compost process
  - Grind coarse materials into smaller bits (communition)
  - Increases surface area: volume ratio
  - Improves access of microbes to organic substrates

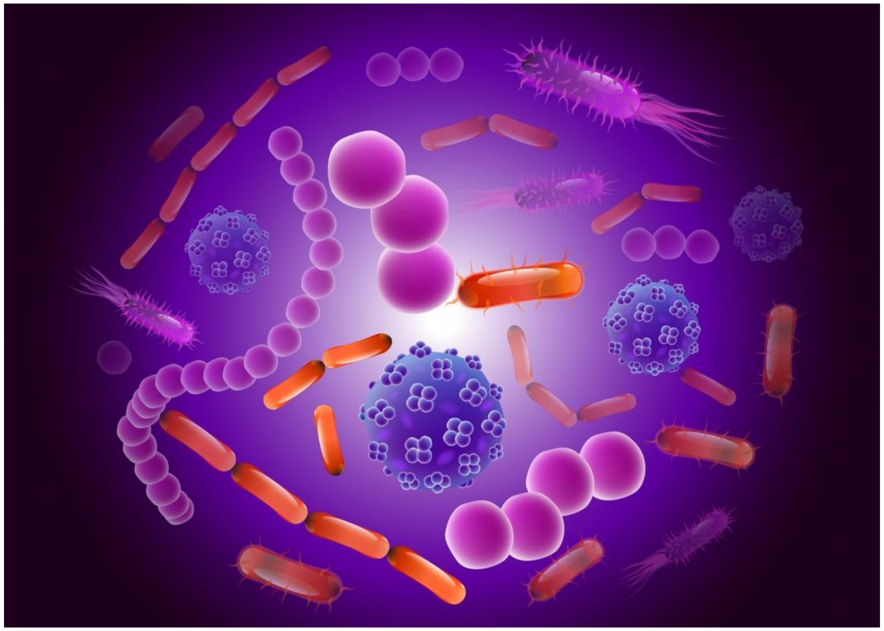
- Protozoa Protozoa
  - Active in the early phases of composting
  - Process smaller bits of organic matter
  - Prey upon microbial populations
    - Regulates numbers
    - Recycles nutrients



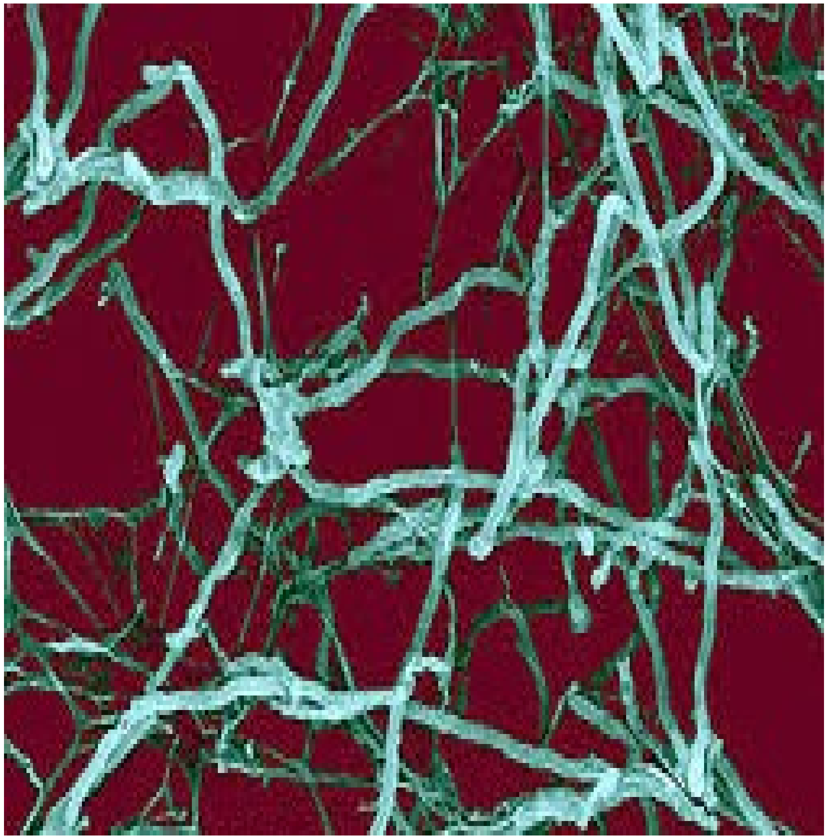
Brachionus calyciflorus

Paramecia

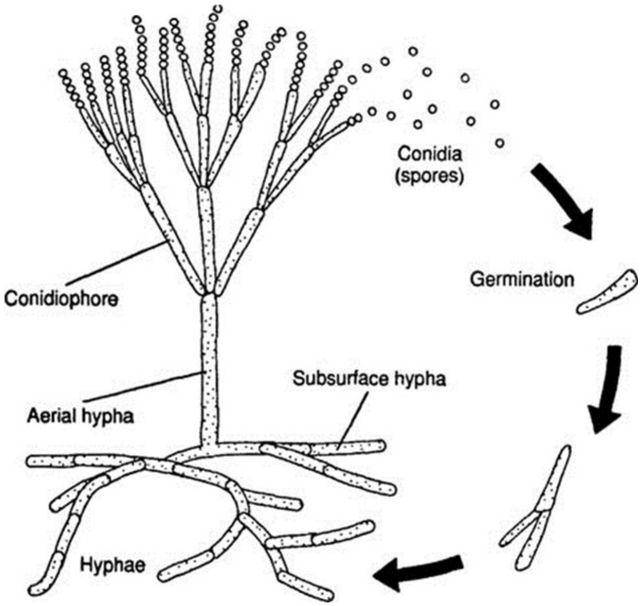
- **Bacteria**
  - Most numerous group in compost
  - Responsible for most of the decay and heat generation in compost
  - Nutritionally diverse



- **Actinomycetes**
  - Filamentous bacteria
  - Produce geosmin
  - Degraders of cellulose, hemicellulose and lignin
  - Important during the thermophilic and cooling stages



- **Fungi**
  - Multicellular eukaryotes
  - Include mushrooms, molds and yeasts
  - Usually filamentous
  - Decomposers of complex plant polymers
    - cellulose,
    - hemicellulose
    - lignin



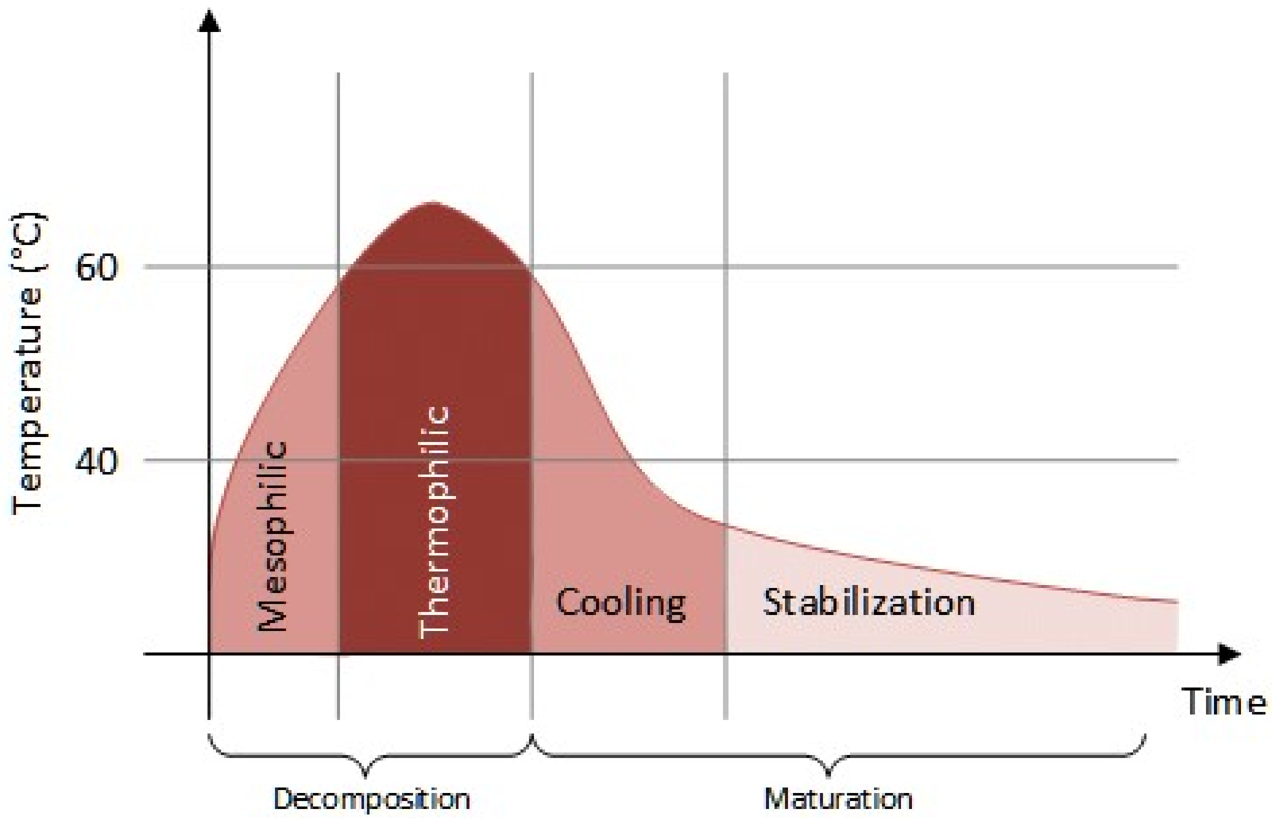
Overview of the compost process

Mesophilic Phase → **Thermophilic Phase** → **Curing Phase**

20 - 40°C
A few days

40 - 65°C, as high as 80°C
A few days to several months

Cooling and maturation
Several months



Stage 1: Mesophilic Stage

- Bacteria and Fungi are key players
  - Fauna and protozoa also important
- Decomposition of readily available substrates
  - Sugars, proteins and starch
- Excess energy is released as heat, causing pile temperature to increase

Stage 2: Thermophilic Stage

- Heat-loving bacteria, actinomycetesand fungi are key players
- Heat intolerant organisms go dormant or are destroyed
  - Human and plant pathogens
- High temperatures accelerate breakdown of proteins, fats, and complex polymers

Stage 3: Curing/Cooling Stage Stage 3: Curing/Cooling Stage

- Mesophilic bacteria, actinomycetes and fungi are key players
- Further chemical and physical changes in the compost
  - Decomposition of recalcitrant polymers by actinomycetes and fungi
  - Degradation of fermentation products, methane, and other noxious gases which accumulated earlier in anaerobic microsites
  - Reduction of odours and toxic intermediates

THANKS