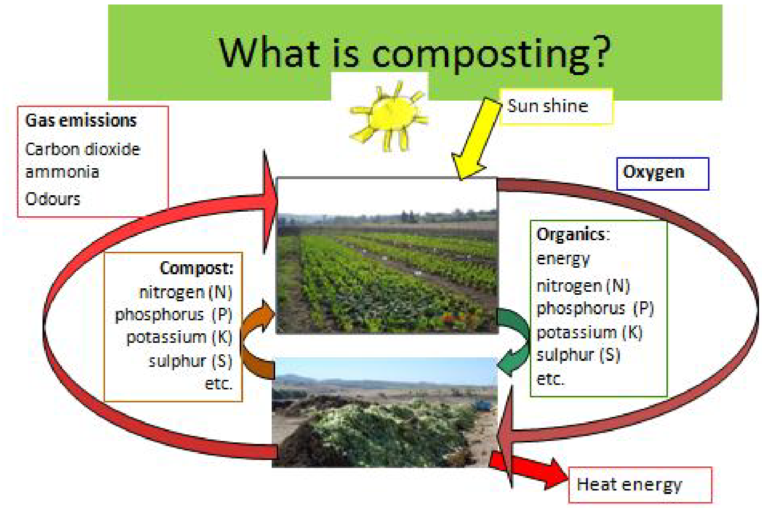
Chapter 4 module 3 Treatment of faeces by composting

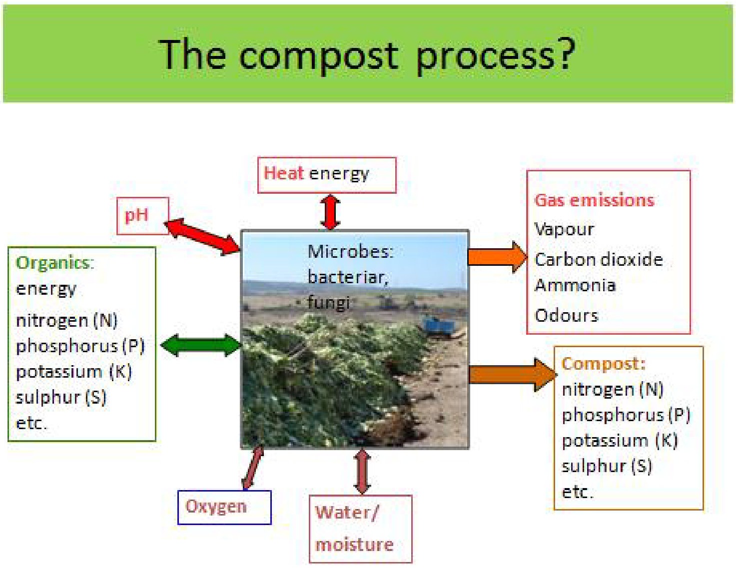
How should urine and faeces be treated for safe handling and reuse in crop cultivation? How can organic material from households be co-treated?

Goal: After the lecture the student should know the principles, prerequisites and main characteristics, properties, advantages and disadvantages of composting of faeces of kitchen waste.



Composting is microbial aerobic degradation of organic material. It is often subdivided into thermophilic and mesophilic composting, where thermophilic composting is performed at 40ºC and above, while mesophilic composting is performed at temperatures below this. Composting is, as shown by the diagram, the reverse process compared to the photosynthesis. In the photosyntesis, organic matter is synthesised by the plants in a process driven by the sun. The plants synthesis many different types of organic substances, e.g. carbohydrates, proteins and fats, which contain a small fraction of the sun energy, which drives the process. The energy stored in the organics in turn drives the whole biological system consisting of herbivores and carnivores, but also the whole system of degrading microbes consisting of bacteria, fungi etc.

In the compost the opposite processes take place as compared to the photosynthesis. In the photosynthesis organic compounds are synthesised from carbon dioxide, water and plant nutrients driven by energy from the sun. In the aerobic degradation in the compost, the organic compounds are degraded by the microbes to carbon dioxide, water and plant nutrients, eg. nitrogen in the form of ammonia, phosphorus, sulphur etc. under the generation of heat.



To optimize the conditions for degradation, the conditions for the growth of the microbes have to be optimised. The composting microbes prefer moist but aerobic conditions with ample supplies of degradable organics.

As shown in the slide, the composting process itself changes its conditions. The heat released during the degradation increases the temperature and this in turn speeds up the degradation. The more of the heat released that is retained in the compost, the more the temperature is increased. Also the pH is affected, as this normally increases to around 8-9 during the process. If the substrate contains a lot of easily degradable organics like a compost containing lots of kitchen waste, then the pH might dip initially, down to about 4-4.5.

The degradation also consumes large quantities of oxygen, and good ventilation is needed to ensure aerobic conditions. The ventilation of an open compost is naturally created as the hot air in the compost expands, which makes it lighter than the surrounding air. The hot lighter air will then raise and create an under pressure of the compost, which is compensated by intake of air from the sides.

Due to the heat, the ventilating air is heated up and due to the ample supply of moisture it is saturated with moisture. This means that water is taken up by the ventilating air and therefore a good thermophilic compost is a drying process.

The plant nutrients contained in the organic substrate is largely mineralised in the compost and for a sustainable plant production, these nutrients should be recycled to the production of crops.

Degradation – compost – digestion

Composting

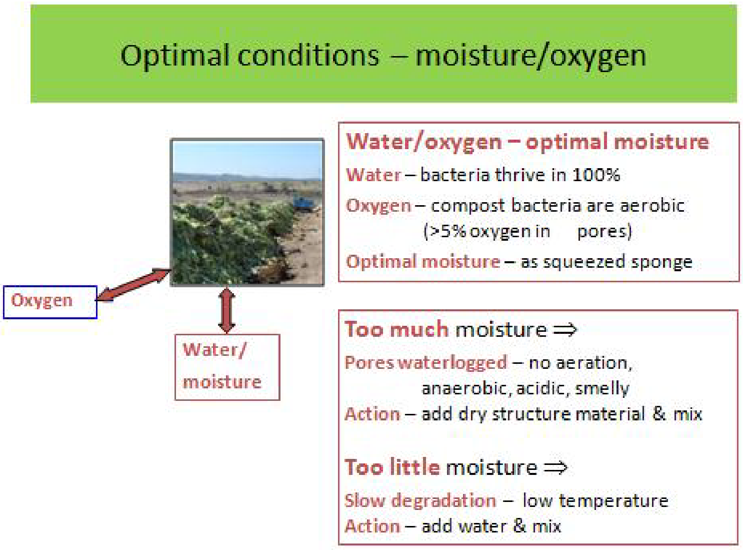
- $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + bacteria
- ΔE= -3880 KJ/mol
- **Energy – appr. half to heat, half to bacteria**

Digestion

- $C_6H_{12}O_6 \rightarrow 3\ CO_2 + 3\ CH_4$ + few bacteria
- ΔE= - 405 KJ/mol
- **Energy – almost all remains in the biogas (-3475 KJ/mol sugar)**

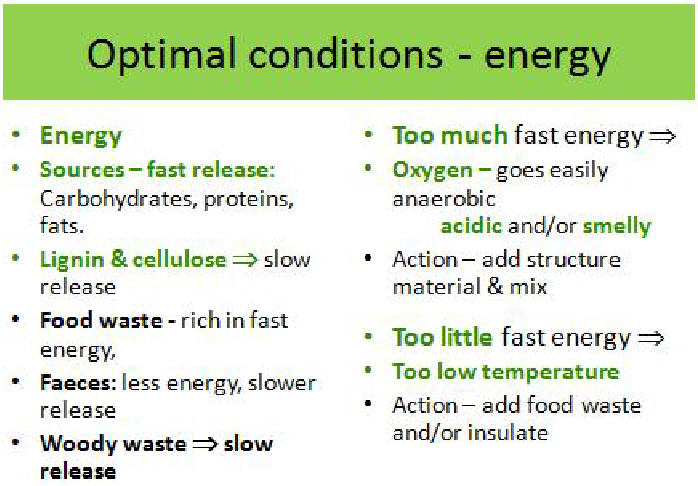
The large heat energy surplus in the composting process means that lots of energy is released and that the bacteria grow very much – as much a half of the initial energy can go into the bacterial cell mass, but as there are several successions of bacteria in a compost, in the end, the bacterial population will contain less energy than this.

By comparison, far less energy is available for the microbes in the digestion process, and thus, they grow far slower and thus the whole process is slower and the heat released is not enough to really heat up the substrate.



As air contains approximately 20.000 times more di-oxygen molecules per litre than water, it is important that the substrate is not too moist, because if it is, the oxygen supply will be limiting and the bacteria run out of oxygen. At the same time the microbes prefer an ample supply of water, as they live in the liquid film on the particles. If there is too much water the pores of the compost will be filled and block out the air to pass.

Thus, for most substrates a good compromise is a moisture content somewhere between 45 and 60% moisture. A simple test on the moisture level is the “fist test”. Squeeze some of the substrate in your hand. If drops of liquid appear between your fingers, then it is too wet. If the substrate falls apart in several pieces when you ease the squeeze, then it is too dry. If it stays in one piece when you ease the squeeze, but no liquid appears, then the moisture level is correct.



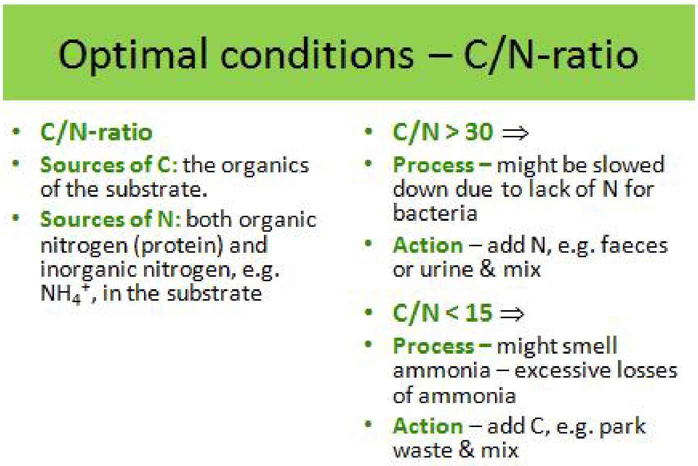
The energy in the compost comes from the material and is released by the biological and biochemical degradation. The energy can be divided into two main categories, fast and slow energy. Food waste that contains carbohydrates (e.g. bread, sugar) proteins (e.g. meat, legumes) and fats (e.g. meat grease and oil) are rich in fast energy while garden waste contains more lignin and cellulose that is degraded slower and thereby contain less available energy.

Compared to food waste are faeces containing less fast energy as most of the energy has been taken up by the body.

Enough fast energy is needed for a high enough rise in temperature, if the temperature raises, the produced amount energy are larger than the energy lost from the compost via ventilation and the surface.

With too much fast energy the process will be so fast that there is risk for oxygen depletion and bad smell, this can most easily be dealt with by addition of better structure to the material and by mixing.

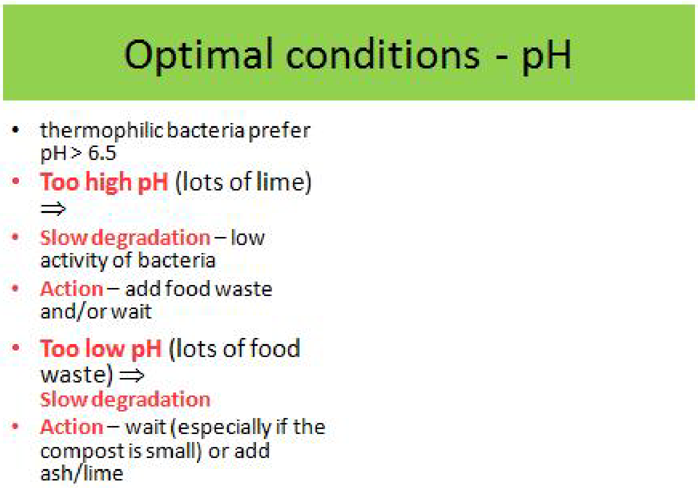
Too little energy content, i.e. no or slow increase in temperature can be compensated by addition of more high energy material such as food waste or by compensating the energy loss by improving the insulation.



The optimal C/N ratio in a composting process is between 10 and 30. In this range there is enough nitrogen per carbon for having an efficient process.

With high C/N ratio >30 the concentration of nitrogen is not sufficient for an efficient process and there is a risk for a slower process (degradation will still occur but not at the same rate as when having higher nitrogen concentration). Action to increase the activity is to add nitrogen to the compost, e.g. urine or faeces.

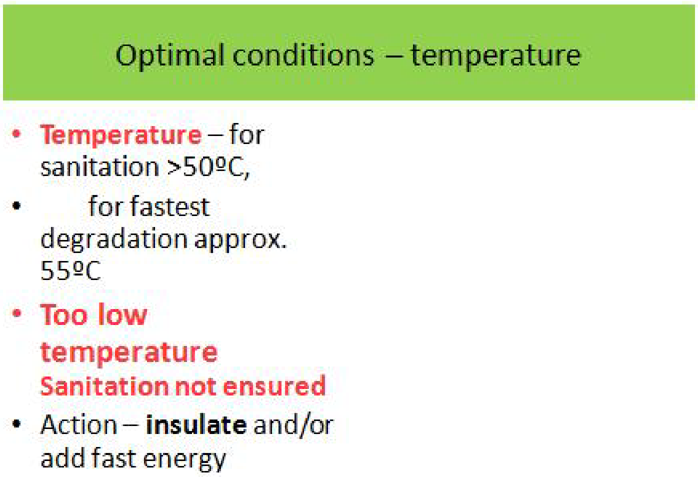
If the C/N ratio goes below 15 does it not really affect the process as the access amount of nitrogen will be emitted as ammonia emission. This can result in smell problems and the easiest way of managing this is adding materials that contain low concentrations of N, e.g. garden waste.



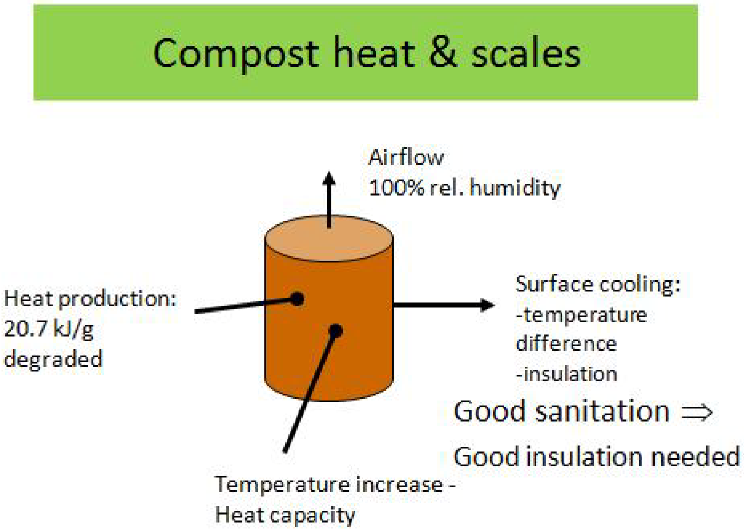
For a high degradation rate, the pH the optimal range is between 6 and about 10. If pH is below 6.5 and similarly the temperature is above 40ºC, then the degradation is very slow.

When composting faeces that have been collected with ash or lime as coverage, the pH can be above 10 and therefore hamper the activity of the compost. This can be compensated for by diluting the material with more organics, e.g. food waste. One other alternative is to wait as the natural processes will decrease the pH as CO_2 from the surrounding air will be collected in the material and slowly decrease the pH.

The compost pH can be too low if the material to compost has been stored and not enough air has entered the system. During the storage there will be anaerobic activities that are producing organic acids, which lower the pH. This will slow down the degradation as low pH has negative effect on the compost bacteria, especially if the temperature of the compost increases. To compensate for this is mainly to wait as the acids will be degraded and the pH will be neutralized. This can take time, especially in larger systems, and the compost pH can be compensated by addition of ash or lime.



A compost temperature of 50-55ºC is normally optimal for degradation. However, temperatures of 70°C and above can be reached and are preferable during sanitation to ensure that as much as possible of the material reaches temperatures above 50°C. For this it is also important that the compost is surrounded by well insulated walls. Further information about compost and sanitisation is presented in chapter 4 module 2.



For good sanitation, as much as possible, and preferable all, of the substrate should reach a temperature above 50ºC. For this, it is essential that the size of the compost is not too small and that it is well insulated. If it is small then the surrounding surfaces become large in relation to the volume and thus in relation to the heat evolved by the degradation in the compost. Thus, the smaller the compost is, the more important it is to insulate is well in order for it to reach at least 50ºC.

Also for a big compost, a good insulation is important in order to maximize the proportion of the compost that reaches high temperatures. If it is not insulated, then essentially all surrounding surfaces will be cool, which means that a large proportion will not reach sanitising temperatures. If the compost is well insulated, then a far larger proportion of compost will reach sanitising temperatures.

Insulation crucial

- Theoretical heat loss
- Heat transfer coefficient:
  - non-insulated: 13 W °C^{-1} m^{-2}
  - Insulated 10cm: 0.053 W °C^{-1} m^{-2}
- so the heat resistance was 25 times larger for the insulated box .

Table: Highest and lowest peak temperature in each box

	Highest	Location	Lowest	Location
Insulated	75.0 °C	¾ depth, near center	57.6 °C	At the air inlet
Non-insulated	49.7 °C	¼ depth, near center	24.9 °C	At the bottom corner

The differences in temperature can be exemplified with the compost above where food waste is composted in two identical 30L boxes where one is insulated with 10cm insulation and the other is not insulated at all. The boxes were placed in room temperature, just above 20 degrees.

When comparing the heat loss from the two boxes it was possible to see a major difference in the heat transfer coefficient, and the heat resistance was 25 times higher in the insulated box.

This can also be exemplified by the difference in temperatures reached in the boxes as the peak temperature, both highest and lowest. The lowest temperature in the corner of the non insulated reactor was very close to the ambient temperature, this indicate that it is important with insulation even in warmer climate as the temperature needed for proper sanitisation is above 50 degrees celcius.

Composts – small scale

These small composts reach high temperatures, thanks to good insulation

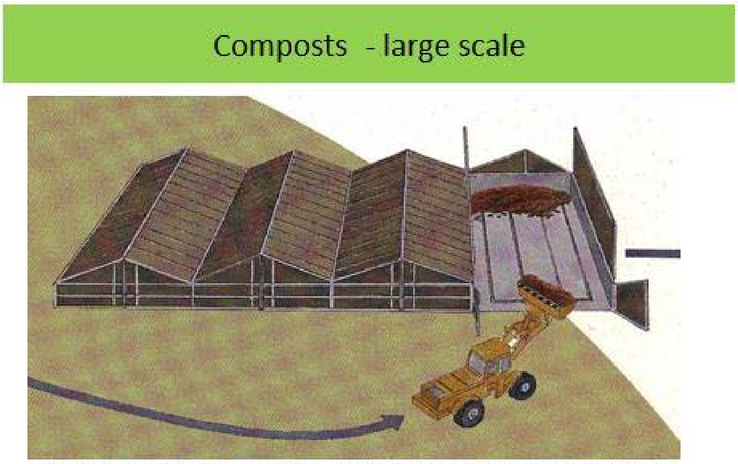
This is examples of small compost reactors (volume ca 200L) used for faecal co-composting with food waste that works well, reaching temperatures high enough for sanitisation. The reason to the good function is the large amount of insulation, 10-20cm of cellplastics on all sides and the top minimising the heat loss.

Windrows can be insulated by their own surface, but for this a height of at least 1.2 metres is required, otherwise the loss to the surface is too high compared to the heat production capacity in the windrow.

The insulation can be improved by using straw or plastic/tarpuline sheets that is put on top of the compost.

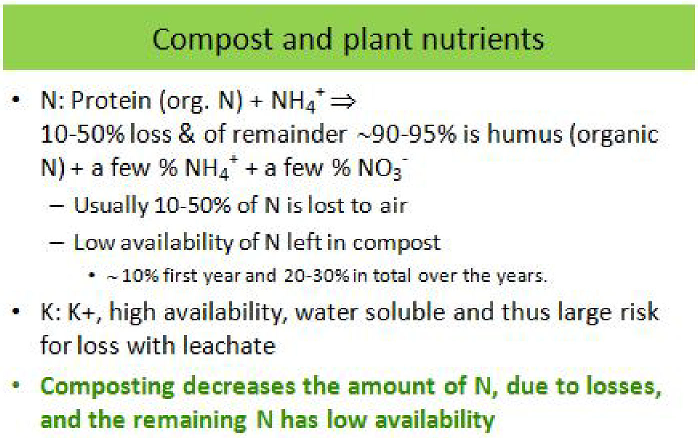
Mixing is also important assuring as large proportion of the material is treated in high temperature. The material in the surface should be mixed into the middle of the windrow during the high temperature process.

As a rule of thumb should a windrow compost be mixed five times and a reactor three times during the high temperature process for assuring good hygiene of the finished compost.



Insulated large scale compost with mechanical aeration

In large scale composts the incoming air can also be pre heated assuring the sanitisation.

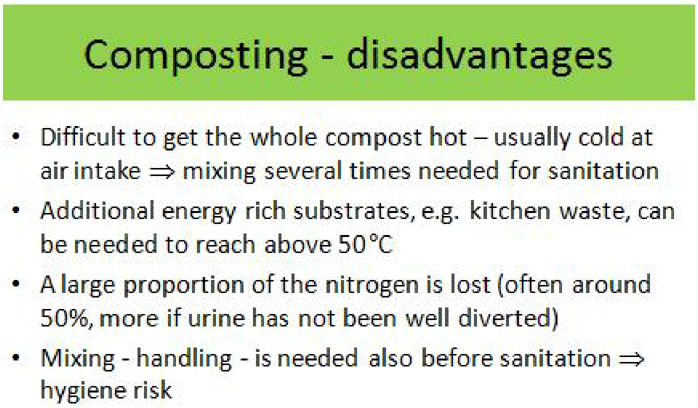


Most nutrients remain in the compost during and after the process, potassium can be lost via leachate due to its high water solubility.

The major loss is nitrogen that will be emitted to the air mainly as ammonia. The ammonia is formed during the degradation of proteins and due to the high exchange of air and high temperature most of the formed ammonia will follow the air out of the compost. If latrine is composted, urine + faeces, the nitrogen loss will be considerably higher as the ammonia nitrogen from the urine will be vented off during the process.

In vermicomposting the process is completely different and the nitrogen loss is considerably less.

The remaining nitrogen in the compost is mainly in organic form and for this to be available for the plants it has to be mineralised by soil microorganisms this takes time and only 10% will be available during the first year and then you can assume that in total 30% will be made available.

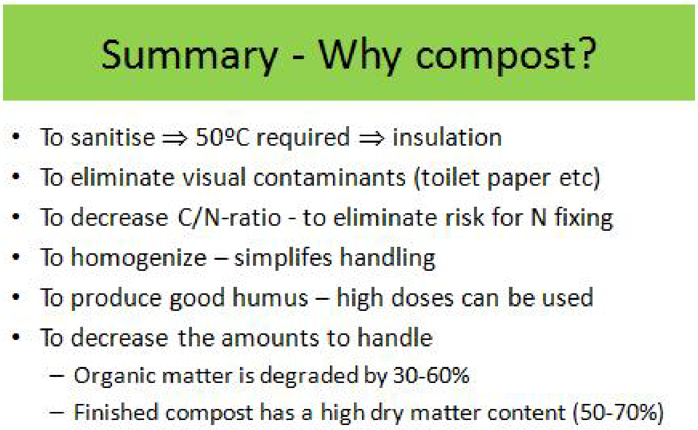


As parts of the compost often is used for insulation there will be parts not heated enough for sanitisation in the compost, even if the centre is very hot. This needs to be compensated for via mixing of the material.

Composting faeces only can reach high temperatures, but the process will be improved considerably by adding food waste. It is important to reach 50°C and above for sanitisation.

Most nutrients will remain in the compost but nitrogen will be lost during the process.

The composting process requires mixing and initial preparation of the compost. During these processes there is a high risk of contamination of the person performing the labor. Information of these risks is important to give to the workers and also provide protective gear and hand washing facilities.



The compost is an efficient method for sanitisation of faecal material if proper temperatures (>50C) are reached.

The finalized compost will have an attractive look as it have a pleasant smell and visual contaminant will be removed. It will also be homogenized and thereby easier to handle and distribute.

The composting process will also decrease the C/N ratio which otherwise can decrease the nitrogen availability in the soil as high carbon loads leads to fixation of available nitrogen into the process of degrading carbon.

The process will also decrease the volume of the material as approximately 50% of the organic material is transformed into carbon dioxide and water.