Composting basics

A practical guide to

composting process management

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1. Introduction: treatment methods for organic waste

The five main ways of recovering organic waste are traditional composting, vermicomposting, anaerobic fermentation (methanization), pyrolysis (production of vegetable charcoal) and combustion (energy use of biomass).

Although they sometimes compete with each other, they should be seen as complementary, each being more or less adapted to the situations encountered. Likewise, the resulting products have different characteristics and complement each other in the effects they are designed to produce.

1.1 Traditional composting

According to the European Environment Agency, composting is "the controlled biological decomposition of organic materials in the presence of air to form a humus-like material". Controlled composting methods include mechanical mixing and aeration, ventilating materials by dropping them through a vertical series of aerated chambers, or placing compost in open-air piles with periodic mixing or turning.

Choosing the right starting mix is essential for a good process. A C/N ratio of between 30 and 40 is optimal. The material must be sufficiently structured to allow good air circulation and avoid anaerobic zones. The starting mix and its structure must be adapted to the chosen composting system.

Composting can be carried out on a small scale (like individual composting) or on an industrial scale. The infrastructure required can be very rudimentary (e.g. a few boards and a fork) or highly sophisticated and virtually automatic. In all cases, good process management is essential to obtain high-quality products (composts) that are beyond reproach in terms of hygienic safety.

The vast majority of the nitrogen contained in compost is in organic form, and is only marginally available to plants in the short term. On the other hand, compost, especially when ripe, has a good medium- and long-term effect on soil structure and water retention capacity, and protects against erosion.

The different types of traditional composting are as follows:

Home composting

- Low infrastructure and investment requirements
- Relatively large amount of manual labour per quantity of compost produced
- Suitable for small quantities of organic residues (up to 10-20 m^3/year)

Field-side composting

- This method is suitable for farmers with small quantities of raw materials (up to 500-1,000 tons per year).
- This method can process both solid manure and green waste.
- No clear separation between the environment (soil) and the compost, making it difficult to ensure that the compost is weed-free.
- Relatively low investment costs, but high labor intensity.

Small windrows (up to 2 m high, 3-4 m wide)

- Suitable for processing solid manure and/or green waste up to 5,000-6,000 tons per year.
- Clear separation between environment and compost.
- Each pile can be managed individually (starting mix, degree of maturation), so that different composts can be produced for different applications.
- Average investment costs. Relatively labor-intensive.
- Requires a relatively large surface area.

Large windrows (up to 3.5 m high, unlimited width)

- Suitable for processing large quantities of solid manure and/or green waste. A sufficient quantity of coarse-structured material is required to ensure good air circulation in the heap.
- Can be used with forced ventilation.
- Clear separation between environment and compost.
- No clear separation between different compost batches.
- Relatively high investment costs, but lower labor requirements compared with smaller windrows.

Small windrows under the roof (up to 2 m high, 3-4 m wide)

- Suitable for processing 5 to 6,000 tons (or more) of solid manure and/or green waste per year.
- Clear separation between environment and compost.
- Clear separation between different batches of compost.
- Work also possible during the rainy or snowy season.
- Relatively investment costs

Composting in halls (approx. 3.5 m high, 20 m wide)

- Suitable for processing large quantities of solid manure and/or green waste.
- With ventilation
- Mechanical windrow mixing possible
- Clear separation between environment and compost.
- No clear separation between different compost batches.
- High investment costs.

Composting in tunnels (approx. 2.5 m high, 5 m wide)

- Suitable for processing large quantities of solid manure and/or green waste.
- Compost turning is controlled automatically.
- Can be used with forced ventilation.
- Clear separation between environment and compost.
- Clear separation between different batches of compost.
- The frequency of turning a batch of compost is fixed (defined by the system).
- High investment costs. Low labor intensity.

Composting in boxes (approx. 3.5 m high, 6 m wide, 20 m long)

- Suitable for processing large quantities of solid manure and green waste.
- Compost turning, forced aeration and wetting are virtually automatic.
- Clear separation between environment and compost.
- Clear separation between compost batches.
- At the start of the process, the distribution of materials in the bin must be homogeneous, otherwise the composting process in a bin will vary greatly from one part of the bin to another.
- High investment costs. Low labor intensity. Limited demand for space relative to quantity processed.

It should be stressed that all these systems can produce good compost, but also poor-quality compost! Process management is essential to quality assurance.

1.2 Vermicomposting

Vermicomposting is a composting technique that uses worms to transform organic waste into a nutrient-rich humus called vermicompost. The technique is well-suited to processing a variety of manures (horse, cattle and rabbit manure), vegetable and fruit waste (kitchen scraps), grass clippings and pre-composted agricultural waste.

With this technique, organic residues do not rise in temperature, so the natural hygienization of the material cannot be guaranteed as in traditional composting. It is therefore important to choose inputs that do not pose problems in terms of weeds and pathogens. In case of doubt, a short phase of traditional composting, with temperature rise, can be carried out to ensure the destruction of weeds and pathogens before introducing them into the vermicomposting system.

Vermicompost is richer in fertilizing elements (such as N, P and K) than traditional compost. This is partly due to the use of more nutrient-rich, low-structure inputs, and partly to the very low ammonia losses that occur during the heating phase of traditional compost.

The juices that may flow from vermicomposting during the process are also rich in fertilizing elements and, diluted, can also be used as liquid fertilizer.

Home worm composting

- Simple system for small quantities of organic residues.
- The bottom of the bins is perforated. When the upper bin is filled with organic waste, the vermicompost contained in the lower bin is ripe. It can be emptied and the upper bin turned upside down to feed the new organic residues. The worms automatically switch from mature compost to fresh material.
- Can be made using wooden boxes or other materials.

Vermicomposting in trenches

- Relatively labor-intensive
- Keeps moisture in the material
- Does not allow juice collection (leaching)
- Do not cover with plastic sheeting (to allow air exchange)

Vermicomposting in layers

- Profitable but labor-intensive
- Take care not to dry out the material (watering).
- Does not allow juice collection (leaching)
- A roof is recommended to protect the system from the elements (rain) and the sun.

Worm composting in beds

- Advantageous infrastructure
- For relatively moderate quantities of organic residues to be treated
- Easy juice collection

Vermicomposting in boxes

- Relatively labor-intensive
- Maintains moisture in the material
- A roof is recommended to protect the system from the elements (rain) and the sun.
- Openings must be left at the bottom of the walls to allow aeration of the material.
- A leachate recovery system can be installed.

Semi-automatic vermicomposting system

- Relatively costly, but labor-intensive
- Handles large quantities of organic residues

1.3 Anaerobic fermentation (methanization)

During anaerobic digestion, organic residues are processed in the absence of oxygen (anaerobic conditions). The result is the production of methane, a gas that can be used as a source of energy, and of liquid or solid digestates (i.e. the products resulting from the liquid/solid separation of digestates: a digestate is solid if its dry matter content exceeds 20%, and liquid if it is less). Basically, anaerobic digestion is primarily a process for breaking down the most labile fraction of organic waste: lignin (wood) cannot be broken down anaerobically.

Digestate is an organic fertilizer containing large quantities of nutrients rapidly available to plants, particularly nitrogen. However, as its organic matter is not yet stabilized and normally contains little lignin, its effect on soil structure in the medium to long term is moderate.

The most commonly used anaerobic digestion processes operate at mesophilic (30-40°C) or thermophilic (50-60°C) temperatures. The anaerobic digestion process is not exogenous, and must therefore be heated to the desired temperature.

Anaerobic digestion involves four microbial processes: hydrolysis, fermentation, acetogenesis and methanogenesis. Different microbial communities are responsible for these processes, and it's important that populations are balanced at each trophic level.

The anaerobic digestion process requires much more technology than composting. It therefore requires a much greater investment than composting, and is more susceptible to various technical problems and other malfunctions

Anaerobic co-digestion

- Treatment of manure with other organic wastes
- Liquid system (5-10% dry matter)
- Generally mesophilic (40-44°C)
- Relatively stable biological process
- Relatively long process (2 to 4 months)

Anaerobic fermentation in boxes

- Batch processing system (weekly emptying and refilling of a can)
- Dry batch anaerobic digestion system
- Generally mesophilic
- Relatively stable biological process
- Average process time required (4-6 weeks)

Industrial anaerobic fermentation

- Continuous dry anaerobic digestion
- Thermophilic, retention time approx. 2 weeks
- Handles large quantities of organic waste

1.4 Pyrolysis (biochar production)

Organic matter (often wood chips) is pyrolyzed in the absence of oxygen at temperatures more than 550°C. The resulting products are charcoal and energy. It is important to control the charcoal production process, otherwise there is a risk of significant formation of organic pollutants (PAHs) during the process.

From a hygienic point of view, biochar is absolutely irreproachable, all weeds and pathogens having been eliminated during the pyrolysis process.

Biochar is known to improve the water retention capacity of soils. It also offers a large ion exchange surface in the soil. Due to its high stability to degradation, biochar can fix large quantities of carbon in the soil over the long term.

However, as biochar contains few fertilizing elements available to plants, it must be activated before use (i.e. loaded with fertilizing elements), otherwise it can lead to the immobilization of fertilizing elements (including nitrogen) in the soil. It can be activated, for example, by adding it to organic residues during composting or methanization.

Artisanal biochar production system

- Batch processing system
- Very little investment required
- Limited possibilities for process control
- With defined and appropriate inputs (e.g. coconut husks), modest quantities of vegetable charcoal of acceptable quality can be produced.
- Average investment costs

Kon-Tiki pyrolysis system

- Batch processing system
- Relatively simple operation, suitable for farmers
- Enables the production of large quantities of charcoal at farm level
- Relatively low investment costs

Semi-industrial pyrolysis furnace

- Batch processing system
- Well-controlled process for producing charcoal of consistent quality
- Average investment costs

Industrial pyrolysis furnace

- Continuous production system
- The process must be well controlled to produce quality charcoal.
- High investment costs

1.5 Combustion (thermal energy production)

Organic material can also be used to generate energy in the form of heat through combustion. However, in the interests of the environment as a whole, the materials used for this purpose must be carefully selected. Woody materials are particularly suitable. Nitrogen-rich materials (manure, dried plant waste, etc.) are unsuitable. Indeed, during drying or combustion, the nitrogen they contain - an essential fertilizer - is largely lost.

To guarantee good quality ash, it is important to control the combustion of materials. Otherwise, organic pollutants (e.g. PAHs) may be produced and end up in the ash.

Combustion ash contains little or no nitrogen, but significant quantities of phosphorus and especially potassium. Its fertilizing value, however, depends on the inputs used. As long as it contains no organic pollutants, ash can be used as a fertilizer (if local legislation permits). One way of facilitating their use is to add them to organic residues at the start of the composting process.

As far as soil fertility is concerned, it's worth pointing out that ash has few positive effects, apart from providing fertilizing elements such as potash and phosphorus. Ash is microbiologically dead and does not influence the biological life of the soil. On the other hand, ash is a mineral product; all organic matter has been mineralized by combustion. Consequently, ash does not improve the soil's humus content or its physical aspects (structure, water retention, porosity, etc.). From an agronomic point of view, it is therefore far less interesting than compost, digestate or biochar.

2. Composting biology

Composting is a biological process involving thousands of micro-organisms. This process is relatively complex, and the role of the master composter is to create and control the conditions necessary for the micro-organisms to do their job optimally. This involves monitoring the process, recognizing potential problems early and taking appropriate action in good times.

Composting means consciously returning organic remains to nature's natural material cycle. Composting is a human-led process involving interdependent conversion processes of organic substances under the influence of soil flora and fauna. It's a sensible way of recycling the organic waste that accumulates, rather than removing it from the cycle by burning it. The main aim of composting is to rapidly create a biologically active humus and thus revitalize cultivated soils. Composting produces a valuable product: compost.

Compost is the solid, crumbly, brownish to dark-brown product of aerobic degradation of biogenic waste or organic matter. A large number of micro-organisms work under the constant influence of air (oxygen) and sufficient moisture in the mixture of materials. In addition to degradation, new compounds are formed. Compost is alive. Compost must be treated like a living organism. This means we have to take care of it. Healthy compost can bring many benefits to soil and plants, but unhealthy compost can be detrimental to plant growth.

To manage composting processes and produce quality composts, it is essential to know and understand the biological basis of the process.

2.1 How does composting work?

During the composting process, organic/biological residues are broken down and transformed by numerous microbes (bacteria, protozoa, actinomycetes, fungi) and small animals (mainly insects, mites and compost worms) with constant access to air (oxygen) and sufficient moisture in the material. It's these useful organisms that do the work. Our sole responsibility is to create the ideal conditions for them to do their job optimally.

Composting micro-organisms. From left to right: bacteria, fungi, actinomycetes.

Composting can be divided into two phases: the degradation phase (with heat development) and the maturation phase (with stable humus development).

- The degradation phase with heat development is very important for the destruction of pathogens and weed seeds in the compost. That's why it's important to turn the compost at least three times during this period, so that every part of the compost is under the influence of this heat. During the degradation phase, it's mainly the bacteria that are active. They feed on organic matter that is relatively easy to digest. However, bacteria are unable to break down the lignin (wood).
- During the maturation phase, the woody matter decomposes, and stable humus is formed. Nitrification also takes place during this phase. During the maturation phase, fungi and actinomycetes do most of the work. While fungi can degrade wood, actinomycetes are responsible for breaking down difficult substances such as chitin (e.g. hair).

For the composting process to take place, two elements are essential:

- carbon (energy source)
- nitrogen (basis for protein formation)

If the ratio between available carbon and nitrogen (C:N ratio) is too high (too much carbon), micro-organisms don't have enough nitrogen to develop their populations, and the degradation of organic matter cannot take place efficiently. If the C:N ratio is too low (too much nitrogen), the available nitrogen cannot be used and is lost in the form of gaseous emissions; in this case, there are also often undesirable odor emissions. Woody materials have a high C:N ratio, while low-structural materials (salad leaves, grass clippings, etc.) have a low C:N ratio.

The C/N ratio at the start of fermentation should be between 30 and 40.

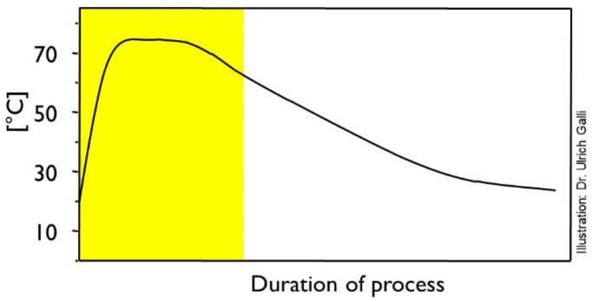
2.2 How do composting parameters evolve?

To guarantee the production of good compost, it's important to control the entire process, from the collection of green materials to the storage and use of the final product. In particular, it's important to monitor the parameters of the composting process to ensure that it runs as smoothly as possible.

C:N ratio of various organic residues

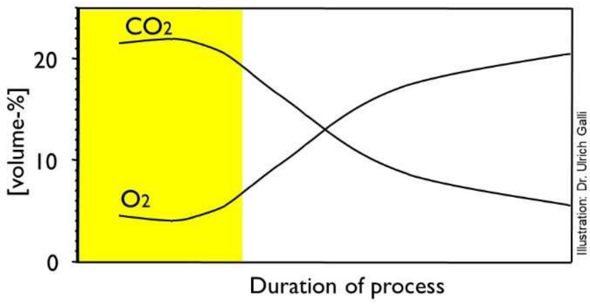
Organic residues	*C:N ratio*
Urine :	*0.8*
Feathers :	*4 – 5*
Chicken manure :	*8 – 10*
Grass:	*12*
Mature compost :	*12 – 15*
Young compost :	*15 – 18*
Cow manure :	*15 – 20*
Kitchen waste :	*23*
Ideal C:N of the starting mixture :	***30 – 40***
Tree leaves :	*50*
Straw :	*50 – 150*
Wood (sawdust) :	*200 – 500*

a. Temperature



Due to the intense activity of the bacteria, the temperature in the center of the compost heap rises rapidly and can reach values more than 70°C. The optimum temperature for good hygienization of the material and optimal biology is between 60 and 70°C. If the mixture of organic residues is too rich in easily degradable matter, or if its humidity is too low, the temperature can rise to over 80°C. This is detrimental to the microbiological quality of the compost produced, as microorganisms beneficial to soil life cannot survive at such temperatures. If the starting mix does not contain enough nitrogen in relation to carbon, or if the material is too moist to allow air to circulate, the temperature remains below 50°C and the natural hygienization of the material is not ensured.

b. Composition of the gas in the compost heap



The composition of the gas inside the compost heap varies during the process. Ambient air contains around 79% nitrogen and 21% O_2, while CO_2 is close to 0.

Due to the intense activity of micro-organisms during the hot phase, the amount of CO_2 in the gas mixture increases and the amount of O_2 decreases. As long as oxygen is present in the air, the sum of

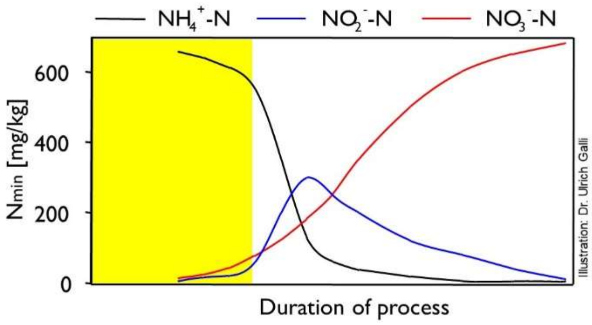
CO_2 and O_2 is around 21%. As ripening progresses, microbiological activity decreases, leading to an increase in oxygen and a decrease in CO_2.

For the composting process to be optimal, the oxygen content in the atmosphere of the compost heap must be at least 4-5%. It's also important to ensure that oxygen is distributed evenly throughout the pile, so that each piece of material receives sufficient oxygen. It's particularly important to prevent the formation of lumps by turning the compost efficiently, otherwise anaerobic conditions may be present in these lumps. To ensure that aerobic conditions are present throughout the pile, it is advisable to measure the methane (CH_4) content in the pile - this can be done using a portable gas analyzer. The absence of CH_4 indicates a homogeneous distribution of oxygen in the heap.

As mentioned above, oxygen demand is much higher during the thermophilic phase of the composting process. It is important to maintain a minimum level of oxygen in the compost at all times during this phase in order to guarantee a high positive biological quality. However, it is also important to maintain a sufficient level of oxygen during the maturation and storage phases, otherwise compost quality can be severely reduced.

c. Inorganic nitrogen content in compost

Nitrogen (N) in composts is mainly present in the form of organic nitrogen, which is less available to plants. However, most of the nitrogen taken up by plants is in the form of mineral nitrogen. Three forms of mineral nitrogen are relevant in compost: ammonia (NH_4-N), nitrite (NO_2-N) and nitrate (NO_3-N). The concentration of these three forms changes during the composting process.



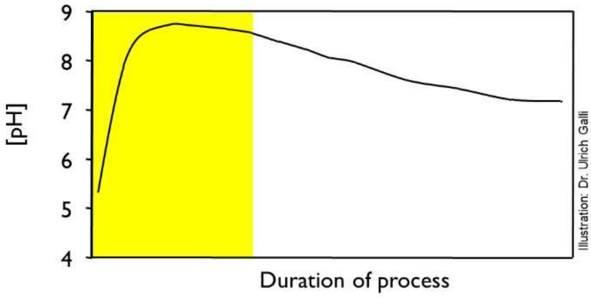
NH_4-N is the first form of mineralized nitrogen found in compost when organic matter is decomposed. NH_4-N is soluble in water, and when the water content becomes too low, NH_4-N is lost as it transforms into gaseous NH_3 (ammonia).

NO_3-N. During the ripening process, nitrification continues and NH_4-N is converted to NO_3-N. If a lack of oxygen occurs during ripening or storage, bacteria can use an oxygen molecule from the NO_3 and convert it back into nitrite (NO_2; toxic to plants) or nitrous oxide (N_2O; potent greenhouse gas).

NO_2-N is a phytotoxic intermediate that appears during nitrification. It can also result from the denitrification process due to lack of oxygen at the end of the maturation process or during compost storage.

d. pH value

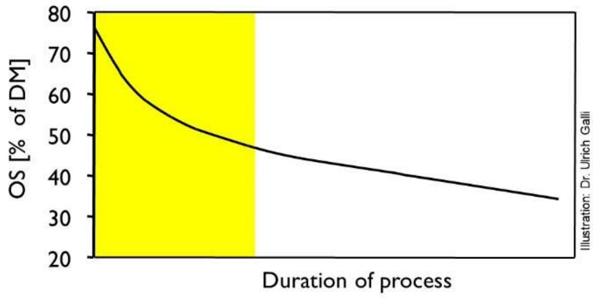
During the first few days of the process, the pH of the material is acidic due to the formation of organic acids. Then, with the release of ammonium into the material as a result of protein decomposition, the pH value rises sharply, reaching values of up to 9. During nitrification, the pH drops to around 7.5.



As the normal value of compost is basic, i.e. above 7, and it is well buffered, it is not suitable for acid-loving plants.

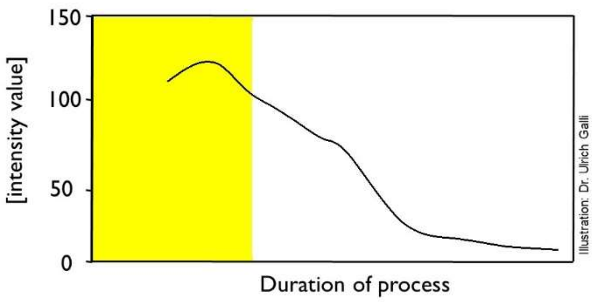
e. Organic substance

During composting, organic matter is mineralized. Organic matter therefore decreases over the course of the process. This reduction is greatest at the start of composting, during the heat phase with its intense activity, and then stabilizes. The organic matter content is between 70 and 80% at the start of the process, depending on the materials processed. Mature compost has an organic matter content of around 30.



f. Color of compost extract

The color intensity of the aqueous compost extract is important for the use of compost as a component in potting soil. For example, if compost with a dark colored extract is used in a flowerpot, there is a risk of undesirable staining of the house wall or soil.



The water extract of young, lignin-rich compost is dark, becoming lighter in color with increasing maturity. This is because the humus molecules present in young compost are small and water-soluble. As the compost matures, micro-organisms build up more complex humus molecules that are no longer soluble, making the extract lighter in color. The color of young compost extract also depends on the composition of the starting mix.

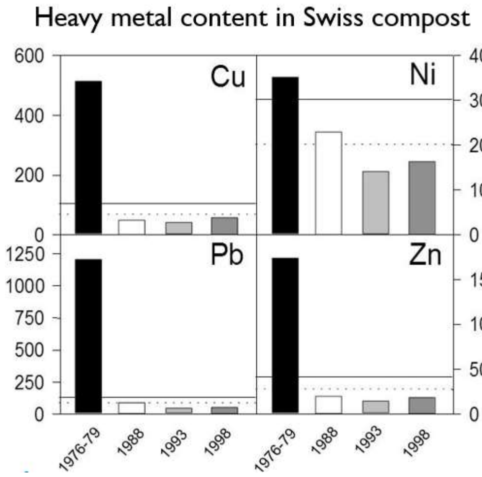
3. Practical management of the composting process

The production of quality compost, which can be used in agriculture to improve soil fertility and plant growth and health, is only possible with optimum management of the process. It should be emphasized here that management of the composting process is not limited to the compost heap itself, but begins with the quality of the inputs used, through to the concept of compost utilization, control of the composting process itself and storage and packaging of the resulting products.

3.1 Composting input collection concept

The quality of the organic residues processed is the basis for producing high quality composts that are useful for soils and crops. To guarantee the quality of inputs, it is essential to sort them at source. This is not only to avoid visible undesirables such as plastics and bits of aluminum, but also because of pollutants such as heavy metals.

Until the late 70s, mechanical-biological treatment (MBT) was used in Switzerland: unsorted municipal waste was composted, with undesirable substances eliminated as far as possible at the end of the process. The quality of the compost produced was very poor. In the early 1980s, Swiss legislation prohibited this type of treatment and only allowed composting of source-separated organic waste. As a result, the heavy metal content of the composts produced fell sharply



a. Source separation of organic waste: everyone's responsibility

The composting facility is responsible for the organic waste it processes. However, optimum results can only be achieved in close collaboration with all those involved in the production, collection and transportation of these organic residues. Dialogue between these partners is therefore essential.

A study of the specific situation is the first step in developing and implementing an organic waste collection concept. In this assessment, socio-economic aspects are just as important as technical ones.

- Animal manure, slurry and other organic residues from agricultural operations
  From the point of view of undesirable substances and organic pollutants, manure and other organic residues from farms are relatively unproblematic. However, depending on the concept used for animal care, their dejecta may be laden with antibiotics or dewormers.
  What's important, in terms of quality, is that these materials are collected as freshly as possible, and not dried out; in fact, by drying out, manure loses much of its available nitrogen in the form of ammonia.

- Organic waste from the food industry
  In general, organic waste from the food industry is relatively clean, provided it is collected before being packaged. However, a study of the waste production process must be carried out to ensure that no problematic substances (such as certain extractants or solvents) have been used and could end up in the collected material. If the organic remains have already been packed, the question of unpacking must be resolved, either mechanically or manually.
  For poorly structured, unstable (rapidly decomposable) products, it's important to collect them while they're still fresh and process them quickly to avoid uncontrolled rotting.

- Waste from retailers and wholesalers
  The problem with these organic leftovers is that they are generally packaged and wrapped. Unpacking these products is not easy, and requires significant investment in machinery and personnel. Indeed, to produce quality compost, it's essential that these products are pure, with no plastic, aluminum or other packaging.

- Organic residues from municipalities
  The organic remains of populations represent a significant quantity of materials to be recycled. In fact, more than half of all household waste is organic. Collection concepts for these residues are discussed below.

b. Organic waste collection from municipalities

Many people are involved in this collection: the municipalities themselves (politically responsible for collection), private households, waste collection companies, haulers and the composting facility. Socio-economic issues are often more important and more difficult to resolve than technical ones.

- Information and education for households
  Household information and education form the basis of separate collection of municipal organic waste. Training/information initiatives must, of course, be tailored to the local situation, the target audience, their level of education, and so on. To be successful, information campaigns need to be repeated regularly. Here are a few examples of possible actions:
  - Use of municipal newsletters or local newspapers: Many municipalities have newsletters with information on planned activities, organized events, infrastructures, rules to be respected, etc. These are distributed to every household and are a good way of communicating the waste sorting concepts implemented by the municipality. These newsletters are distributed to every household and are a good way of informing the population about the waste sorting concepts implemented by the municipality. Articles published in local newspapers can also reach a wider audience.
  - Leaflets were distributed to all households:
  - Posters at waste collection points
  - Short films on YouTube or a similar Internet platform
  - Hiring "waste advisors" to reach out to the public
  - Events with fun activities
  - School courses

- Information and training for waste collection companies and haulers
  Clear guidelines need to be drawn up for organic waste collectors and transporters. The measures described in these guidelines should also be included in the specifications when contracts are signed with these companies. It makes sense to accompany this approach with training courses for these companies' employees. The following points should be defined in these guidelines:
  - Organization of collections to ensure good quality organic residues (frequency, collection systems, collection containers, etc.).
  - Assessing the quality of organic residues
  - Measures to be taken in the event of organic residues of poor quality or contaminated by undesirable substances (e.g. refusal of collection, overcharging for collection, targeted distribution of information sheets, transport of contaminated products to another processing site or landfill, etc.).

- Information and education about composting facilities
  Develop a concept for processing organic waste in the composting facility. This concept can include various points to manage input quality:
  - Evaluation of deliveries, in the event of major problems, refusal to deal with them
  - Separate unloading of hazardous loads with undesirable contents
  - Organization of manual sorting of organic residues to eliminate undesirables prior to grinding or further processing of the material


Municipal collection systems to guarantee organic waste quality

c. Receiving materials and structural equipment on a composter

Receiving raw materials is the first essential point in a composting facility. A well-organized receiving area is essential, as it determines the rest of the composting process. This is where the processed inputs are brought in, sorted, conditioned and then blended to obtain optimal starting mixes for the rest of the process.

Various elements are part of this reception area:

- A scale to determine the weight of the delivered materials. This is particularly important if the delivered materials have to pay a landfill tax or if the composter has to purchase them. If no scale is available, it is possible to estimate the volumes delivered, then transform this quantity into tons using transformation factors depending on the material delivered. The scale can also be used later to sell the compost produced.

- The second important element of a receiving area is the infrastructure for unloading, checking and sorting deliveries. This element naturally varies according to the source of the inputs, and in particular their quality. For example, despite efforts to educate the population, municipal collections are much more contaminated by undesirable materials and therefore require a larger sorting area. The sorting infrastructure can be relatively simple when it can be carried out manually. Where large quantities of inputs require intensive sorting, a more substantial infrastructure may be needed, such as an inlet screen to eliminate large unwanted objects, followed by a conveyor belt to facilitate manual sorting. A magnet system installed at the beginning of the conveyor belt can also be used to remove metals.

Examples of scales:
Manual scale (top left), portable axle scale (top right), axle scale (bottom left), weighbridge (bottom right).

- The third important element of the organic waste reception area is an infrastructure for intermediate storage of the inputs until they are used. This infrastructure must enable the various inputs to be stored separately, so that the starting mixes for the composting process can be produced at a later date. Some inputs, such as wood waste, can be stored for long periods, while others, such as low-structured plant residues, need to be processed as quickly as possible. Depending on the quantities of inputs received and the space available, storage can be in separate piles, which does not require major investment. It can also be stored in boxes, for example.

Examples of infrastructure for sorting delivery scales.
Manual sorting on the ground (top), sieve for coarse plastics removal (bottom left), hammer mill (bottom right).

Examples of intermediate input storage: in stacks (left), in boxes (right).

d. Practical input reception

Inputs must be received in a professional manner. Each delivery must be logged, controlled and recorded. This is particularly important when deliveries are subject to an exchange of money (unloading charge or purchase).

The following points must be recorded in organic waste reception protocols:

- Date of receipt
- Origin (supplier name)
- Type of material
- Quantity of material delivered
- Material condition (fresh or rotten, clean or containing foreign matter, etc.)
- Note if delivery requires intensive sorting

Once entry control has been carried out, it's time to decide where to unload the equipment. In general, between three and five subdivisions are defined for intermediate storage of inputs:

- Sorting area for materials requiring intensive sorting
- Storage area for woody materials to be crushed (wood), rich in carbon and suitable for long-term storage.
- Storage area for carbon-rich materials that do not require grinding (e.g. coconut fibers).
- Storage area for cow manure / chicken manure
- Storage area for low-structural, nitrogen-rich materials to be processed as quickly as possible (e.g. municipal waste, marinating waste).

Depending on the situation, the storage of these materials can be subdivided. The aim of this subdivision is to be able to precisely and simply create the starting mix for the composting process.

e. Input preparation

Once the inputs have been received, they can be conditioned and used to prepare the starting mix for the composting process. The two main points are as follows:

- <u>Removal of all undesirable materials</u> from the input material (stone, plastic, metal, glass, aluminum, etc.). This operation must be carried out before any other operation, such as grinding the material. Indeed, with each operation, undesirable materials such as plastics are reduced to small pieces, making disposal more difficult and time-consuming.
- <u>Shred coarse materials</u>. Some materials (wood branches, coconut husks, etc.) need to be crushed before composting. As these materials are rich in carbon, but can be stored for a relatively long period, they can be shredded periodically, e.g. every 4 or 6 weeks. As good shredders are expensive and often oversized for a small or medium-sized cooperative, a professional shredder can be called in from time to time to perform this operation. It's important to note that woody material must be defibered, not cut, during this operation. For this reason, a hammer mill or slow screw crusher is generally used. If the material is cut, the relatively smooth surfaces obtained do not allow the micro-organisms responsible for composting to attack them effectively.

Preparing wood for the composting process.
Top: defibered wood, suitable for composting. Bottom: chopped wood, not suitable for composting.

3.2 Setting up a compost heap

For the composting process to be a success, it's essential to set up the compost heap. The three most important points are as follows:

- C/N ratio of starting mixture
- Starting mix structure
- Water content

a. C/N ratio of starting mixture

As described in chapter 2.1, an optimum C/N ratio in the starting mix is essential for good, harmless microbiological activity. If the ratio is too high, the microorganisms won't have enough nitrogen to thrive, and the composting process won't get off the ground. If the ratio is too low, on the one hand, excess nitrogen volatilizes and is lost, and on the other, undesirable and noxious odors can be observed. A good starting ratio for the composting process is between 30 and 40.

To obtain a good C/N ratio, the various inputs are mixed. Structure-poor materials (plant residues, urban waste, straw-poor manures, etc.) are generally rich in nitrogen and have a low C/N ratio. Woody materials (wood, coconut fibers, straw, etc.) are rich in carbon and have a high C/N ratio. Woody materials (wood, coconut fibers, straw, etc.) are rich in carbon and have a high C/N ratio.

Here is an example of the "ideal mix":

- 1/3 raw wood (wood chips, sieved compost residues, cut bark)
- 1/3 medium-fine fibrous material (shredded branches, wood fibers, straw, foliage, switchgrass, reed, peat from consumed potting soil)
- 1/3 material, almost without structure (dung, grass, rumen contents, vegetable manure, etc....)

Finally, the use of additives is possible:

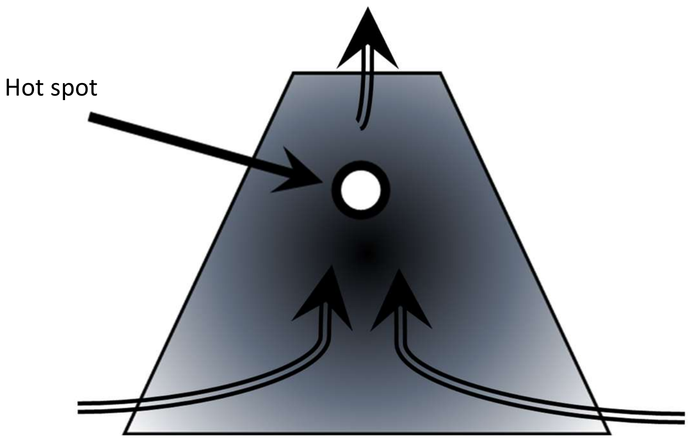
- powdered clay (3-5 kg/m^3), soil (50 liters/m^3) or biochar (50-100 liters/m^3). This buffers the system and optimizes the activity of the micro-organisms. The result is the formation of clay-humus complexes and a particularly lumpy compost structure. It also helps prevent the release of undesirable odors in the event of excess nitrogen.
- enzymes. Enzymes are sometimes offered on the market to reduce odors in large composting plants, or to accelerate lignin decomposition in wood-rich mixes. However, with a good starting mix, the addition of enzymes is not necessary.
- microorganisms. Here too, various micro-organisms are available on the market, with the promise of accelerating decomposition processes. Their usefulness is questionable, however, as they are not necessarily suited to the organic remains being processed. In this respect, the most effective is to add 5-10% mature compost screenings (if the compost is screened) or 5% mature compost to the starting mix. In this way, the starting mix can be inoculated with the micro-organisms best suited to the material being treated.

- Fertilizer: If the starting mixture is very rich in carbon and nitrogen-rich materials (such as chicken manure) are not available, adding small quantities of nitrogen fertilizer can stimulate the composting process. In organic farming, this nitrogen can be added in the form of horn shavings or feather meals (50 to 100 g/m^3).
- the addition of 5-10% of mature compost or screenings produced on site is an excellent way of inoculating the material at the start of the process with micro-organisms specifically adapted to the materials being processed on site. This is particularly important when processing relatively difficult-to-degrade materials such as rice husks or coconut fibers.

b. Starting mix structure

The right structure of the compost heap is important for an optimal process. If the structure is too compact, air cannot circulate, the chimney effect (air intake conditioned by the rise in temperature in the compost heap) cannot take place, conditions in the heap become anaerobic and the production of quality compost is no longer possible. Conversely, if the structure is too loose, air exchanges are too great, the pile is constantly cooled and the temperatures required for the natural hygienization of the material cannot be reached.

The structure of the heap should be adapted to its size: the larger the heap, the coarser the structure of the starting mix should be. For very large heaps (such as tabular windrows), the installation of forced aeration may be advisable.



Hot spot and chimney effect in a compost windrow.

As far as windrow shape is concerned, the triangular shape is the most advantageous from the point of view of natural gas exchange. However, it requires more floor space than a parallelepiped shape. When using such a shape, care must be taken to ensure that air can still circulate evenly. If the pile is relatively large, forced aeration should be considered.

If, for practical reasons, the material to be composted is placed in boxes, it is necessary either to leave openings in the walls of the boxes (especially at their bases), or to install pipes or drilled channels or forced ventilation to allow air to penetrate.

c. Water content

A good moisture content in the compost feedstock is essential for the process to run smoothly.

If the material is too dry, on the one hand the micro-organisms can't work, and on the other the ammonium present in the young material is lost in the form of ammonia and the composting process can no longer take place.

If the material is too moist, air can no longer circulate and the pile becomes anaerobic, leading to the formation of toxic substances and the release of undesirable, unpleasant odors.

The water content of the decomposing material can vary considerably during the composting process if left unchecked. During the hot phase of the process, water losses due to evaporation are very high. It is therefore important to regularly add sufficient moisture to the pile to avoid blocking microbiological activity and significant nitrogen losses in the form of ammonia gas. As the temperature of the compost heap drops as the process advances, so does the need for water. If the compost is too moist during this phase, it is virtually impossible to remedy the situation. It is therefore important to protect the compost from excess moisture during the ripening phase.

To control humidity, the fist test is the most appropriate method. To do this, it's important to take material from inside the pile. The test is performed as follows: take a handful of compost and squeeze it as hard as you can between your fingers. If water runs out, the compost is too moist. Open your fingers. If the compost ball disintegrates, the compost is too dry. If the compost ball remains compact, the compost is perfectly moist. Moisture status should be recorded in the process control logbook on the following scale: -3 (completely dry), 0 (optimal), +3 (completely moist). It is important to check the moisture content of the material before each mixing operation, to determine whether the windrow needs to be watered before or during mixing. To do this, the material in the center of the pile should be checked, not the surface of the pile, as the latter is not representative. Where appropriate, the quantity and source of water supplied should be noted in the protocol.

Fist test to determine the water content of compost
Left: compost too moist. Center: compost with optimum moisture content. Right: compost too dry.

d. Swath covering

To protect the organic matter being composted from drying out (in periods of drought) or from excess water (in periods of rain), windrows should be covered. However, it's important not to cover them with plastic sheeting, but with special compost cloths that allow air to circulate. If you cover the windrows with plastic, the convective air created by the chimney effect cannot escape, and the decomposing matter suffocates. This has a very negative impact on the biological composting process and on the quantity of compost produced.

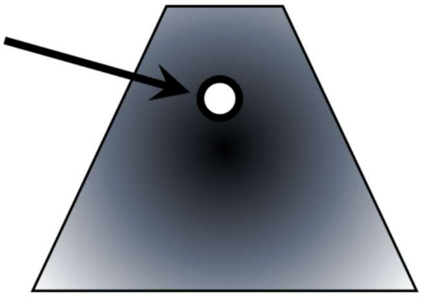
Covering compost windrows
Left: conversion with hermetically sealed plastic sheeting: unsuitable for composting.
Right: cover with breathable compost fleece: suitable for composting.

3.3 Controlling the actual composting process

The management of the composting process is essential for the production of quality compost suitable for the desired use. This begins with the preparation of the starting mix (chapter 3.2) and the installation of compost heaps, and extends to the storage and packaging of the product (chapter 3.4).

a. Monitoring temperature trends

To monitor the activity of the process, it's important to periodically (once a week) measure and record the temperature of the hot spot in the compost heap. The evolution of the temperature tells us whether fermentation is proceeding correctly and whether the process is advancing.



Hot zone of the compost windrow, where temperature is measured.

Recording the temperature evolution on the protocol is also important to attest to the natural hygienization of the material if it is not hygienized before the start of the process. Compost is considered hygienized if, after the last addition of fresh organic matter:

- temperature above 55° C for at least 3 weeks
- or higher than 65° C for at least 7 days
- and the compost was turned at least three times during this period to ensure that every part of the material passed through the thermal phase.

The lack of temperature rise in the material can have several causes. Various measures must be taken:

- The compost heap is too small. The surface area of the heap is proportionately very large compared to its volume. As a result, too much heat is exchanged with the surrounding air, and the material doesn't rise in temperature. In this case, you need either to make larger heaps, or to compost in insulated boxes (which still let in enough air for the micro-organisms to work aerobically).
- The starting mix is far too loose and too much air can circulate too easily, cooling the material. This can happen if the woody material is ground too coarsely for the size of the pile. In this case, the shredder must be adjusted to obtain a finer shred.
- The C/N ratio of the mixture is too high, either because there is too much woody matter, or because the inputs have been poorly stored and are already largely rotted or dried out. In this case, nitrogenous materials should be added (chicken manure, grass clippings, or even nitrogenous fertilizers such as horn shavings or feather meals).
- The mixture is far too dry, preventing the micro-organisms from acting. In this case, the material needs to be moistened.
- The mixture is far too moist, preventing air from circulating properly. Without oxygen, micro-organisms cannot function properly. Anaerobic processes take place, with no heat release, but with the development of undesirable, foul-smelling odors. In this case, dry matter must be added to the mixture.

The ideal temperature for producing quality compost is between 60 and 70°C during the warm phase. However, it is possible for the temperature of a compost heap to rise above 80°C, which has a negative impact on the biological quality of the product, as the micro-organisms that develop their change. The larger the compost heap, the greater the risk.

- The main cause of this temperature rise is a mixture containing too much nitrogen-rich, easily degradable material (e.g. chicken manure or grass clippings). To avoid this problem, create a mixture that is less rich in these materials (by adding more woody matter). Adding clay soil (around 5%) can also buffer the system and mitigate this risk.
- Another frequent cause of uncontrolled temperature rise is the drying out of the material during the composting process. When humidity is too low, and nitrogen is available in sufficient quantities, exothermic chemical reactions can occur, causing the compost heap to self-ignite. It is important to ensure that the compost heap is sufficiently moist, and to add water if necessary.

Temperature measurements must be documented, in particular to attest to the natural hygienization of the compost (process protocol).

b. Compost heap moisture management

As mentioned above, moisture management of the compost heap during the composting process is essential for the production of quality compost.

To check humidity, it's important to take material from inside the heap. This can be done using the Hand Moisture Test (see chap. 3.2.c): take a handful of compost and squeeze it as hard as you can between your fingers. If water runs out, the compost is too moist. Open your fingers. If the compost ball disintegrates, the compost is too dry. If the compost ball remains compact, the compost is optimally moist. The moisture status should be recorded in the process control logbook on the following scale: -3 (completely dry), 0 (optimal), +3 (completely moist). It is important to check the moisture content of the material before each mixing operation, to determine whether the windrow needs to be watered before or during mixing. If necessary, the quantity and source of water supplied should be noted in the process control protocol.

Compost needs a lot of water during the hot phase. When the temperature drops, you need to be very careful about watering the compost, as it no longer evaporates much water, and risks becoming too moist.

c. Compost heap aeration management

Sufficient oxygen in the compost heap is essential to enable aerobic micro-organisms (such as fungi) to do their work. A minimum of 4% oxygen must be ensured in the heap throughout the composting process, and also during storage of the finished product. In the absence of oxygen, anaerobic conditions also lead bacteria to produce malodorous molecules (such as organic acids).

To ensure adequate air supply, the starting mix must be sufficiently structured to allow air to circulate. The wider the swath, the coarser the structuring material and the greater the quantity required.

To ensure an adequate supply of air, compost must be turned periodically. The frequency of turning depends on the material and the size of the pile. At the start of fermentation, turning should be once or twice a week. It's not the oxygen from turning in the composting material that's important; it's rather the re-establishment of the optimal windrow structure, which allows air to circulate through the material (chimney effect). Later, when the high volume loss of material is over, biological activity diminishes and the frequency of turning can be reduced.

The use of a gas analyzer helps optimize process management to ensure sufficient oxygen content throughout the compost heap. This measuring device is particularly useful for forced aeration and for managing the storage of finished products.

Measuring gas composition in a windrow.

d. Mixing compost heaps

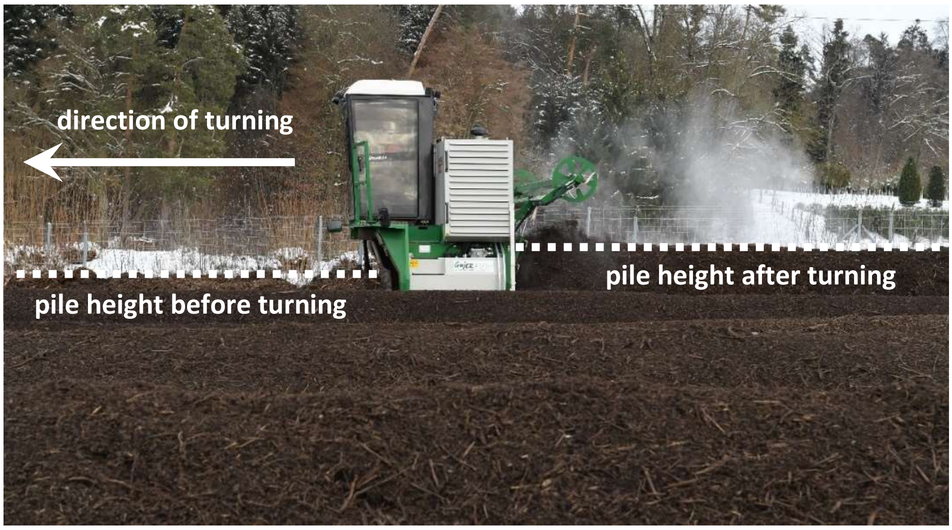
Turning the compost is important to ensure a good supply of oxygen to the material. Turning the compost is also important for obtaining a homogeneous product. By mixing the intermediate degradation products, compost turning also activates the biological activity of the process.

The water content of the heap is also adjusted during heap mixing operations (by adding water if necessary).

The optimum solution for mixing a compost window is to use a compost mixing machine. If such a machine is not available on the composting site, the windrow can also be mixed using a loader. However, care must be taken to shake the bucket well when emptying it to obtain the loosest possible windrow after this operation, and not to roll over the compost to avoid compacting it.

For small compost heaps, it is of course possible to turn them by hand using a fork.

Turning the compost piles.
Left: manual turning with a fork.
Right: turning with a mechanical mixing machine



Effect of compost turning on compost heap structure.

e. Process control protocol

A process monitoring protocol must be drawn up for each load of compost. compost. It must contain the following information:

- batch number and installation date
- mixture components (in m^3 or % of mixture)
- addition of any additives (soil, enzymes, micro-organisms) (in quantity).
- date of additions
- subsequent addition of inputs with quantity and date of addition
- process log (temperature, humidity, O_2 content if possible),
- operations carried out, such as turning, adding water, covering the swath with geotextile, ...
- when adding water, note on the protocol which quality of water (local water, river water, rainwater, etc.) has been added and in what quantity.
- -where applicable, the date of sampling for quality analysis.
- subsequent batch processing (sieving, packaging, storage, etc.)

The monitoring protocol must always be carefully kept up to date. In particular, it serves as a basis for monitoring the natural hygienization of the compost produced in the plant, and for optimizing the process.

Example of a composting process control protocol

Name of the composting plant	Batch no:
Total quantity of the starting mix [m^3]:	Batch location n°:

Setting the rent

Date	Input 1 .... [m^3]	Input 2 .... [m^3]	Input 3 .... [m^3]	Input 4 .... [m^3]	Input 5 .... [m^3]	Input 6 .... [m^3]	Remarks

Date of compost screening:	Delivery of the compost:

Monitoring the process

Date	Temperature [°C]			Humidity 0: OK; -1: dry; -3: very dry +1: wet; +3: very wet			Implementation	H_2O [liters]	Sampling	Remarks	Visa
	T1	T2	T3	F1	F2	F3					

3.4 Product conditioning

Once the composting process is complete, the compost has to be conditioned to meet the needs of users, then stored until delivery.

Depending on the desired use and duration of use, different packaging and storage operations are required. These must be carried out in conjunction with quality control of the composts produced (see chapter 4).

a. Compost sieving

The main conditioning operation consists of sieving the compost to obtain the desired granulometry for its intended use. Care must be taken here not to sieve the compost too finely. Not only is this costly, it also detracts from the beneficial effects of the compost. After all, it's the woody fractions that enable the formation of long-lasting humus in the soil. The finer the sieving, the more this fraction is eliminated. So, for field crops or arboriculture, a 20 or 30 mm sieve is quite sufficient. For potting soil production, a 10 mm sieve may be desirable.

If the compost contains plastic particles or other undesirable substances (glass, aluminum, etc.), screening operations can remove them manually or by placing a plastic vacuum cleaner at the coarse fraction outlet.

On this point, it's important to communicate with the compost user and explain that compost is not a chemical fertilizer and doesn't need to be sieved very finely to look like one.

Whenever possible, it's a good idea to sieve the compost as late as possible before use. In fact, the structuring matter present ensures better natural aeration of the material.

For small quantities of compost, it can be sieved by hand through a sieve. For larger quantities, a rotary or star sieve can be used (chapter 6.1d).

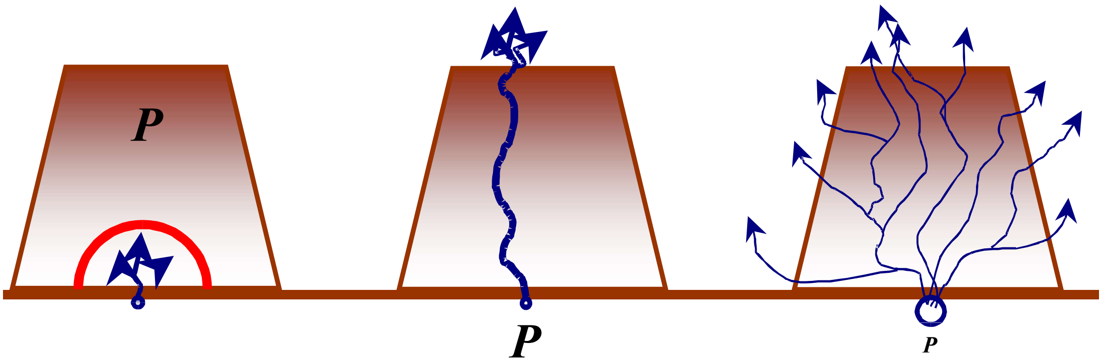
b. Compost storage

During storage, it's essential to ensure sufficient aeration of the compost, otherwise it will suffocate and greatly reduce its quality. It is therefore preferable to store compost in heaps. If the pile is small (up to 1.5 meters high), ambient air circulation is sufficient to ensure good oxygenation. If the pile is larger, you need to either install forced aeration, or continue to stir the pile regularly every two to three weeks (depending on its degree of maturity).

The installation of a forced ventilation system is essential. If the compost heap is too compact, air cannot spread through it. If the pressure of the air leaving the aeration pipe is high, the air takes a preferential path, and compost outside this path is not aerated. For good aeration, the air must leave the aeration pipe at a low pressure; in this case, it can diffuse well throughout the pile. By measuring the oxygen level in the compost heap, you can adjust the optimum aeration regime (e.g. 5 minutes per hour).

The forced ventilation system can be built using relatively simple techniques.

During storage, compost must be protected from the elements. The more mature the compost, the more susceptible it is to be waterlogging.



Installation of a forced aeration system under a compost heap.
Left: the compost heap is too compact, and air can't get out of the aeration pipe.
Center: the pressure of the air leaving the vent pipe is too high: the air chooses a preferential path.
Right: air flows out of the low-pressure aeration pipe, easily diffusing into the compost.

Example of compost heap aeration.
Left: ventilation with drilled tubes laid in the ground. Right: ventilation rail installed in the ground.

Example of compost storage to protect it from bad weather

Mature compost doesn't need much oxygen. However, it is important to ensure that a minimum amount is available. Various factors are important: the size of the storage pile (the larger the pile, the greater the oxygen supply to all materials), the stage of maturity of the product (the more mature the compost, the lower its oxygen requirements), the humidity (the wetter the compost, the more difficult it is for air to circulate), the use of additives (the more compost is mixed with mineral materials (such as field soil), the lower its oxygen requirements).

Effect of storage on compost quality and plant compatibility.
Above: compost stored with sufficient oxygen supply.
Bottom: the same compost deprived of oxygen during storage.

c. Final compost conditioning

Delivering compost in bulk makes the most sense in terms of quality. If, for logistical reasons, it is necessary to bag the compost, this should be done as late as possible before delivery (do not store compost in bags for several months), and choose bags that allow air exchange (woven bags are preferable).

The bags should be stored in the shade and, if possible, in a cool place, so that the quality of the compost deteriorates as little as possible during storage.

d. Production of compost-based mixes

Compost-based soil mixes are generally requested according to the field of application. This is particularly true for seed production, horticulture and landscaping. In order to meet the expectations and needs of users of this type of product, it is important to establish a dialogue with them to define the specific characteristics of these mixes.

To ensure the quality of soil products, it is advisable to set up a simple field laboratory (see chapter 4.5c). In this laboratory, regular analyses of intermediate products should be carried out throughout the production process. Parameters that change during the production process are examined: pH value, salt content, NH_4-N, NO_2-N and NO_3-N. In order to obtain relevant values for mixtures as quickly as possible, samples should be analyzed as soon as possible after collection.

The choice of other ingredients in the mix is important. Soil is often an important part of the mix. Soil can come from fields or construction sites. It is important to ensure that the soil is free of weeds and problematic pathogens. Nor should it be too heavy; a clay content of between 25% and 25% is generally optimal.

Other ingredients can be mineral (sand, crushed bricks, perlite, etc.) or organic (coconut fibers, hemp fibers, glumes, etc.). Here too, the quality of these ingredients must be beyond reproach (absence of pesticides, high salinity, weeds, pathogens, etc.).

When developing these compost-based products, it is advisable to carry out pot trials with plants to test and optimize these mixtures.

Compost-based mixes available to users

4. Product quality assurance

Characterizing the quality of the composts and digestates produced is essential for choosing the right product for the right use, and for optimizing utilization strategies.

While the evaluation of parameters evolving during the composting process can be carried out with simple means and a field laboratory (see chapter 4.5c), other analyses, required by legislation, must be carried out by a certified laboratory.

For the results obtained to be relevant, however, it is essential that the sample taken is representative of the compost batch.

4.1 Taking a representative sample of compost

a. Taking a sample from a compost windrow

Using an auger ("simple edelman auger, sand type", diameter 10 cm, minimum length 100 cm), make a cross-cut to the center of the swath every 10-15 meters (depending on the length of the swath). For small swaths: make at least 5 cuts per swath. If you don't have an auger, you can also use a shovel to make holes in the windrow, ensuring that they are sufficiently deep.

b. Taking a sample during sieving

Take approximately 1 2-litre sample every 15 m^3. For smaller batches, take a minimum of 5 samples.

c. **Taking a sample from a compost heap**

Using the auger, take one deep sample (up to approx. 80 cm) per 15 m^3 of compost. For smaller piles, take at least 3 samples.

d. **Final sample preparation**

Spread the compost on the plastic sheet and mix well. Take the required amount of compost: around 1 to 2 liters for chemical analysis. Place samples in plastic bags. Clearly mark sample bags (sampling date, batch number, compost age). Send the sample by the quickest route to the analysis laboratory. For analysis of the various forms of inorganic nitrogen, the sample must be cooled and kept cold (4°C) until analysis.

4.2 Legal analysis required

The analyses required by law vary from country to country. This point needs to be clarified for each country. In particular, the number of analyses legally required per year needs to be clarified.

The analysis methods required may also vary from country to country. Normally, certified laboratories use the official analysis methods of their country.

It is essential to clearly define with the laboratory the form in which results are delivered (g/kg MF, g/kg MS, g/m^3 material, etc.). This must be clearly indicated in the laboratory report.

In general, the following analyses are required:

a. **Agronomic data (important, among other things, for drawing up the manure balance)**

- dry matter (DM) [in % FM]
- specific weight [kg/m^3]
- organic matter (OM) [in % DM].
- salinity [in g KCl_{eq}/kg TS] or [in mS/cm (with indication of extraction method)].
- pH (with indication of extraction method)
- C/N ratio
- total nitrogen [in kg N/t DM] [in kg N/t DM]
- total phosphorus [in kg P_2O_5/t DM] or [in kg P/t DM].
- total potassium [in kg K_2O/t DM] or [in kg K/t MS].
- total calcium [in kg Ca/t MS]
- total magnesium [in kg Mg/t DM].
- total sulfur [in kg S/t MS].

b. **Environmental protection data**

- Lead [in g / t MS]
- Cadmium [g / t MS]
- Copper [in g / t MS]
- Nickel [in g / t MS]
- Mercury [in g / t MS]
- Zinc [in g / t MS]
- Plastic foreign matter [wt.% MS]
- foreign material glass [weight % MS] and foreign material metal [weight % MS]

4.3 Interpretation of agronomic data

Agronomic data is important for planning the optimal use of composts.

The C/N ratio and organic matter content are indications of the product's degree of maturity and stability.

pH value and salinity are important parameters for the use of composts in horticulture and potting soil manufacture, as various ornamental plants are sensitive to excessively high pH or salinity values.

The fertilizing elements N, P_2O_5, K_2O, Ca, Mg and S are important for defining the quantities of products to be used for the various crops and for drawing up manure balances.

As shown in Table 1.1 (values for Switzerland as an example), the fertilizer requirements of different crops vary considerably. To avoid over-fertilization, the nutrient N, P or K covered first by the compost determines the amount of compost to be added to the soil; specific commercial fertilizers must be added to supplement the requirements for other nutrients. An exception is made for peas: as this legume does not require nitrogen, it is not included in the manure balance. Of course, this calculation must be updated according to the fertilizer content of the composts used and the needs of local crops.

Quantities of compost required to cover crop needs (example: fertilization in Switzerland). (in yellow: fertilizers limiting the quantities of compost to be added to avoid over-fertilization).

	Fertilizer content (green waste compost CH) [kg/m^3]	*Wheat*		*Corn*		*Potatoes*	
		Needs [kg/ha]	*m^3 compost /ha*	*Needs [kg/ha]*	*m^3 compost /ha*	*Needs [kg/ha]*	*m^3 compost /ha*
N_{tot}	*4.6*						
Available	*0.5*	*140*	*280*	*110*	*220*	*120*	*240*
$P\ O_{25}$	*2.0*	*63*	*32*	*103*	*52*	*82*	*41*
$K\ O_2$	*4.3*	*81*	*19*	*235*	*55*	*448*	*104*
Mg	*1.8*	*15*	*8*	*25*	*14*	*20*	*11*

	Fertilizer content (green waste compost CH) [kg/m]^3	*Sunflower*		*Peas*		*Apple trees*	
		Needs [kg/ha]	*m^3 compost /ha*	*Needs [kg/ha]*	*m^3 compost /ha*	*Needs [kg/ha]*	*m^3 compost /ha*
N_{tot}	*4.6*						
Available	*0.5*	*60*	*120*	*0*	*0*	*60*	*120*
$P\ O_{25}$	*2.0*	*49*	*25*	*78*	*39*	*20*	*10*
$K\ O_2$	*4.3*	*394*	*92*	*154*	*36*	*80*	*19*
Mg	*1.8*	*55*	*31*	*20*	*11*	*15*	*8*

4.4 Data interpretation for environmental protection

Environmental data is important to ensure that composts can be used sustainably without causing medium- or long-term problems for soil fertility, crop quality or the environment.

This data must comply with the legal guidelines of the various countries before composts can be used in agriculture. These limited values differ from country to country.

Requirements for the use of these products in organic farming may be more stringent. Organic certification offices can provide information on this point.

Each country also has guidelines concerning the number of analyses required annually to monitor these limit values. In general, these are based on the quantities of material processed.

Limit values for heavy metals and foreign matter in recycled fertilizers in Switzerland.

Pollutant	*Limit value for conventional agriculture*	*Limit value for organic farming*
Lead (Pb)	*120 [g/kg MS]*	*120 [g/kg MS]*
Cadmium (Cd)	*1 [g/kg MS]*	*1 [g/kg MS]*
Copper (cu)	*100 [g/kg DM]*	*100 [g/kg DM]*
Nickel (Ni)	*30 [g/kg MS]*	*30 [g/kg MS]*
Mercury (Hg)	*1 [g/kg MS]*	*1 [g/kg MS]*
Zinc (Zn)	*400 [g/kg MS]*	*400 [g/kg MS]*
total foreign substances (metal, glass, etc.)	*0.4% of the weight of the of dry matter*	*0.4% of the weight of the of dry matter*
aluminum foil and synthetic materials (plastics)	*0.1% of the weight of the of dry matter*	*0.05% of the weight of the of dry matter*

4.5 Additional product quality parameters

In addition to analyses carried out by certified laboratories, the quality of composts during the composting process must be assessed on site. This can be done by a number of simple means:

- control of process parameters
- assess compost quality using your own senses
- compost quality assessment using a field laboratory
- compost quality assessment using plant tests (biotests)

a. Process parameter monitoring

The first important point in product quality control is the evaluation of the process control protocol (chapter 3.3e). The most important point is the evolution of the material's temperature, to ensure that the conditions required for the product's natural hygienization are guaranteed. As a reminder, its temperature has been above 55° C for at least 3 weeks or above 65° C for at least 7 days, with at least two turnovers during this period to ensure that every part of the material has passed through the thermal phase.

b. Assess compost quality with your own senses

Observing compost with your own senses (eyes, nose, touch) can provide information on compost quality. These observations cannot replace chemical analyses or plant tests, but they can complement them.

- Compost color

At the start of the composting process, the material presents a mosaic of colors derived from the input materials. During the process, a homogenization of color occurs and, as humification progresses, the compost becomes brown or blackish. If the compost is too dry during the process, gray mold may be observed.

View of organic matter at the start of the composting process (left) and mature compost (right).

- Compost smell

Compost always smells, but odors can be more or less intense and more or less pleasant depending on the management process. The smell of compost depends on its maturity and the management process. Young composts containing nitrogen-rich materials smell of ammonia, and will transform during the maturation process into a product with a forest-land odor. Unpleasant odors such as "rotten eggs" or butyric acid are typical of poorly controlled anaerobic processes in the compost heap. Organic acids are formed for lack of oxygen and cannot be transformed downstream, resulting in the emission of intense, unpleasant odors.

- Compost structure

Mature compost produced by an optimal process has a crumbly structure and no recognizable starting material apart from a few pieces of wood. The presence of a lot of fibrous material is a sign that the compost is not sufficiently mature. This can happen if the moisture content of the compost heap is too low, especially in the warm phase. The ammonium present in the pile would then be lost in the form of ammonia, resulting in a lack of nitrogen for micro-organisms and insufficient decomposition, even if water is available. When such fibrous compost is applied, there is a risk of nitrogen immobilization in the soil.

- <u>Wood fracture test</u>

The wood breakage test also characterizes the compost's degree of maturity and the risk of nitrogen immobilization in the field after use. Wood degradation begins after the high-temperature phase. We therefore observe minor wood degradation in young compost, and clear wood degradation in mature compost. If relatively raw wood is applied to a field soil, the micro-organisms responsible for its degradation will immobilize the nitrogen available in the soil in order to carry out the degradation. This nitrogen is then temporarily unavailable to plants, inhibiting their growth.

Fibrous compost (left) and friable compost (right).

Wood fracture test

*Left: young compost, in the heating phase.
The wood is still hard, white to light in color, and shows no signs of deterioration.*

*Middle: Compost at the beginning of the maturation phase.
The wood is slightly soft, darkens at the edges and is a little oily.*

*Right: Mature compost.
The wood is soft, the fracture surface is dark and the edges black, and water can be easily extruded by squeezing the piece of wood.*

- <u>Content of undesirable substances in products</u>

The content of undesirable matter (mainly plastics) in compost can already be assessed by simple observation. This is particularly important for a farmer wishing to buy compost, as it can help him choose the different qualities he wants to add to his fields.

For the compost producer, this evaluation is important in order to optimize the process if necessary. Various measures can be taken if necessary, such as better sorting of inputs or finer sieving of the finished product.

- <u>Color of aqueous extract</u>

To carry out this evaluation, 50 g of compost are stirred for an hour in 500 ml of water, then filtered. Young compost still contains small humus molecules, which are soluble in water: the color of the extract is very dark. During the maturation process, micro-organisms build up large, water-insoluble molecules from the small ones: clear water extract.

Assessment of undesirable matter content in composts
Left: compost with lots of plastic; right: clean compost

c. Assess compost quality using a field laboratory

With a relatively simple field laboratory (see Appendix 1 "Chemical analysis of compost in a field laboratory", Fuchs, 2022), dry matter, salinity, pH and inorganic nitrogen (ammonium, nitrite and nitrate) can be determined. This data, which changes over the course of the composting process and compost storage, provides important information on the possible uses of composts.

The procedures for carrying out these analyses are also described in Appendix 1 "Chemical analysis of compost in a field laboratory", Fuchs, 2022.

In particular, the available forms of nitrogen present in the compost enable us to assess the state of the composting process (degree of maturity) and whether the compost has suffered from any problems during the composting process or during storage

d. Evaluate compost quality using plant tests (biotests)

The advantage of biotests is that plants react to all aspects of compost quality, not just to certain parameters such as those mentioned above. The results of biotests are visible to the naked eye and enable simple evaluation. By carrying out biotests, the compost/digestate producer develops a different relationship with the product, which often results in an improvement in the quality of the composts produced.

Biotests are a good tool for public relations activities and to enable constructive dialogue with compost users.

- These tests can be carried out by the composting plant itself. Plants react differently to compost quality. It is therefore useful to carry out several tests on plants in parallel, depending on the question to be developed: open and closed cress test (general quality assessment), lettuce test (general quality assessment), bean test (indicates whether a lack of oxygen has occurred during compost maturation), ryegrass test (indicates the risk of nitrogen immobilization by the compost).

Interpretation of compost quality by comparing levels of different mineralized forms of nitrogen

Relative content of form N min1			*Interpretation*
NH -N4	*NO -N2*	*NO -N3*	
-	-	-	*No nitrogen available. Mixture too rich in carbon, or all the NH_4-N has been lost due to lack of moisture. Risk of nitrogen immobilization in the field.* *Recommendation: add N-rich material to the mix (digestate, turf, chicken litter, etc.).*
+++	-	-	*Very young compost, nitrification has not yet begun.* *Recommendation: keep the mixture sufficiently moist to avoid NH_4-N losses and allow nitrification to take place.*
+++	++	+	*Young compost, incipient nitrification.* *Recommendation: keep the mixture sufficiently moist to avoid losses of NH_4-N; ensure a constant supply of oxygen to the mixture.*
+	++	+++	*The compost is almost ripe and nitrification is almost complete.* *Recommendation: make sure there is a constant supply of oxygen to the mixture.*
-	-	+++	*Mature compost, nitrification complete.* *Recommendation: make sure there's a constant supply of oxygen in the mixture Compost is ripe and ready to use.*
-	+++	++	*Mature compost, nitrification complete, but lack of oxygen during storage*

- : none (< 10 mg N / kg DM); + : small quantity (10-50 mg N / kg DM);
++: medium quantity (50-200 mg N / kg DM); +++: high quantity (> 200 mg N / kg MS)

In general, two tests are carried out with watercress: the open watercress test and the closed watercress test (see Appendix 2: Fuchs, J.G., Weidmann, G. 2018. Determining compost quality using watercress tests. PRACTICAL ADVICE NO. 054 from the OK-Net Arable project, www.ok-net-arable.eu). If watercress seeds are not available in the country concerned, other plants (such as lettuce) can be tested.

- Open cress test

The open cress test is not very sensitive, and only poor-quality composts score badly in this test. In this test, cress growth in pots (Ø 10 cm) filled with compost is compared with growth in commercial potting soil.

- Growth in compost < 50% of growth in reference substrate: compost not very compatible with plants.
- Growth in compost > 75% of growth in reference substrate: compost with good plant compatibility.

- <u>Closed cress test</u>

The closed cress test is very sensitive, as the cress seeds are not only in contact with the compost, but also with the gases released from it. Only high-quality composts perform well in this test. For this test, PVC cans (1 liter) are half-filled with compost potting soil, cress is sown in them, then the cans are hermetically sealed; the length of the roots in the compost and in a commercial potting soil is then compared.

- growth in compost > 25% of growth in reference substrate: compost moderately compatible with plants.
- growth in compost > 75% of growth in reference substrate: compost with high plant compatibility.


Phytotoxicity tests to assess the compatibility of composts with plants.
Left: open cress test. Right: closed cress test.

e. Conclusions

To guarantee the production and optimum use of high-quality compost, it is essential to implement an effective quality assurance concept. This concept must not be limited to the composting process itself, but must start with the collection of organic waste and go right through to the use of the composts produced.

Of course, the various parameters can interact, and different soils and climatic conditions can also influence the reactions of composts after application. It is important to take these points into account when making an overall assessment of compost suitability

Assessing the suitability of compost for different uses

Parameters	*Effect of fertilization*	*Effects on soil organic matter and structure*	*Disease suppression*	*Culture medium component*
Compost color				
• *mosaic of colors*	--	--	--	--
• *even color*	++	++	++	++
Odors				
• *ammonia*	+	-	-	--
• *bad (e.g. rotten eggs)*	--	--	--	--
• *forest soil*	+	++	--	++
Compost structure				
• *very fibrous*	--	0	-	--
• *friable*	++	++	+	++
Wood fracture test				
• *wood still hard*	--	-	0	--
• *slightly soft wood*	--	0	+	--
• *piece of tender wood*	++	+	++	++
Process temperature				
• *hygienization is not achieved*	-	-	--	--
• *hygiene achieved*	+	+	++	++
Heavy metal content				
• *above legal limits*	--	--	--	--
• *compliance with legal limits*	++	++	++	++
pH value in extract $CaCl_2$ 0.01M 1:10 w:w				
• *> 20 g KCl_{eq}/kg TS*	0	0	0	--
• *10-20 g KCl_{eq}/kg TS*	0	0	0	-
• *< 10 g KCl_{eq}/kg TS*	0	0	0	++
N_{min} extract content $CaCl_2$ 0.01M 1:10 w:w				
• *< 100 mg N_{min}/kg TS*	--	0	-	--
• *100-160 mg N_{min}/kg TS*	-	0	0	0
• *> 160 mg N_{min}/kg TS*	++	+	+	++
Open cress test				
• *< 50% compared to control*	0	0	--	--
• *50-75% compared to control*	0	0	0	--
• *>75% compared to control*	0	0	++	++
Closed cress test				
• *< 25% compared to control*	0	0	0	--
• *25-50% compared to control*	0	0	+	0
• *>50% compared to control*	0	0	++	++

--: not suitable for this purpose; 0: not relevant; ++: suitable for this purpose

5. Vermicomposting

Vermicomposting is a technique for composting low-wood organic waste, such as peelings and coffee grounds. Manure can also be processed by vermicomposting.

Vermicompost is rich in fertilizing elements, partly because of the inputs used and partly because nitrogen losses are minimal with this system.

An important point to consider is the hygienic aspect of the compost produced. During vermicomposting, the material does not rise in temperature as in traditional composting, and the natural hygienization of the material (destruction of weeds and pathogens) cannot therefore be ensured. This is why it's important to use only inputs that present no hygienic risk, or to subject them to a short heat treatment phase to hygienize them before adding them to the vermicomposting system.

As the name vermicomposting suggests, compost worms do the work, in collaboration with bacteria and fungi. Compost worms are epigeic worms, meaning they live in the surface litter and feed on decomposing organic matter. There is a wide variety of compost worms. The most common is *Eisenia foetida*, but other worms can also do the same job: *Eisenia andrei*, *Lumbricus rubellus*, *Megascolex mauritii*, *Eudrilus eugeniae*, *Perionnyx excavatus*, *Lampito mauritii*, etc.

Generally speaking, vermicomposting is a continuous process: the worms digest organic matter; once this has decomposed, they switch to fresh organic matter to continue their work. In a vermicomposting system, we therefore have mature vermicompost on one side, fresh organic remains on the other, and between the two the organic matter being decomposed by the worms.

Under optimal conditions, compost worms' cycle from cocoon to cocoon over a period of 2 to 3 months.

5.1 Vermicomposting systems

There are many ways of practicing vermicomposting, from small family household waste processing systems to semi-automatic industrial systems: home vermicomposting, trench vermicomposting, bed vermicomposting, wedge vermicomposting systems, box vermicomposting, semi-automatic vermicomposting systems (see chapter 1.2).

The choice of vermicomposting system depends mainly on the quantity of organic waste to be processed, and the surface area and infrastructure available.

5.2 How vermicomposting works

Generally speaking, all vermicomposting systems work in the same way. After being briefly attacked by mold, the organic remains are digested by compost worms. Once the organic matter has been digested, the worms switch to fresher material. A regular migration of worms is thus observed.

In practice, this means that mature vermicompost is on one side of the system, digesting material in the middle and fresh material on the other.

Mature compost, which contains virtually no worms, can be harvested and used, while fresh material is regularly added on the other side of the system.

In systems where the layers of material are stacked vertically (box or crate systems), a movable-bottom grid (scraper) can be installed at the bottom of the system to collect the mature vermicompost. If this is not possible, when the box or crate is full, the top layer of material (containing the worms) is transferred to an empty box (or crate), where the mature vermicompost can be collected.

In trench, layer or wedge systems, the system can be organized so that fresh material is always added at one end of the material, with worms advancing in that direction, and mature compost at the other end of the system.

5.3 Requirements for vermicomposting

Compost worms need the following elements to grow and be active:

- a favorable environment ("litter"). This material must be highly absorbent to remain sufficiently moist, not too dense to allow good air circulation, and have a low nitrogen content (high carbon/nitrogen ratio). The layer of fresh material should not be too thick, so that its temperature does not rise as in a traditional compost heap. Suitable materials include horse manure, hay, straw, vegetable peelings and coffee grounds.
- feeding. Compost worms consume more than half their body weight every day, 15% of which is eliminated in the form of worm excrement (vermicompost).
- Sufficient humidity. Since compost worms breathe through their skin, humidity levels below 50% in the bedding are dangerous. Optimum humidity for vermicomposting is between 70% and 90%.
- sufficient aeration. Compost worms breathe and cannot survive in anaerobic (oxygen-free) conditions.
- controlled temperature. Compost worms can survive at temperatures as low as 0°C, but will not reproduce at temperatures below 10°C and consume little food. The optimum temperature for vermicomposting is between 20 and 25°C. At temperatures above 35°C, worms have difficulty surviving.

Other parameters are also important for the development of compost worms:

- pH. Worms can survive in a pH range from 5 to 9, the ideal range being between 7.5 and 8.0.
- Salt content. Worms are very sensitive to salts and prefer salinities below 0.5%.
- Other contaminants toxic to compost worms include dewormers (often found in horse manure), detergents and certain chemicals and pesticides, as well as tannins found in certain trees, such as conifers.

5.4 Installation of a vermicomposting system

Basically, there are two different vermicomposting systems: vertical vermicomposting and mobile vermicomposting.

In the vertical system, fresh material is added in successive layers, starting at the bottom of the vermicomposter. Once the bottom layer of material has been digested, the compost worms move on to the upper layers of fresher organic matter. To harvest the mature vermicompost, either the vermicomposter is equipped with a perforated moving bottom, or the top part of the vermicomposter (containing the compost worms) is moved to a new, adjacent vermicomposter to harvest the vermicompost in the lower layers. It's important to add fresh material to the vermicomposter regularly, depending on the worms' rate of digestion. If too much is added, the material can heat up or become compacted, hindering the activity of the compost worms.

In the itinerant system, a 30-40 cm heap of organic residues to be processed is created and inoculated with compost worms. Fresh material is then added to one side of the pile. Once the compost worms have digested the first slice of material, they move on to the fresher parts. The first slice of vermicompost can then be harvested.

For both systems, once production has started, the compost worm population adapts to the inputs being processed. If no problems arise, there's no need to add more worms. Fresh material inputs must be adapted to the worms' working speed.

When setting up a vermicomposting system, worms need to be added. Worms can be found in other vermicomposting systems or in nature, for example in fresh bedding in a field or forest, or in a manure pile. Until the worm population has developed, only modest quantities of fresh material should be added.

5.5 Vermicomposting management

Compost worms have a multiplication cycle of 2 to 3 months. So, when setting up your system, if you can't get large numbers of worms, start slowly. The amount of fresh material added should be adapted to the worms' ability to multiply. After a few months, if the system is set up correctly, the worm population will become very large and so will the system's capacity.

It's important to maintain the right level of humidity. The material must be well moistened to allow good worm activity, but not too much, otherwise the material will not aerate properly and the worms will dry out. The fist test (chapter 3.2c) can also be applied to regulate this humidity.

To ensure good aeration of the material and drainage of excess juices, it is advisable, in systems with a vertical succession of layers, to install a grid or perforated floor on the bottom of the material to allow excess juices to drain off and air to penetrate. Excess juice can be used as liquid fertilizer.

Adding around 5-10% of fine, dry soil to the fresh material is beneficial to the process. This buffers the system and encourages worm activity.

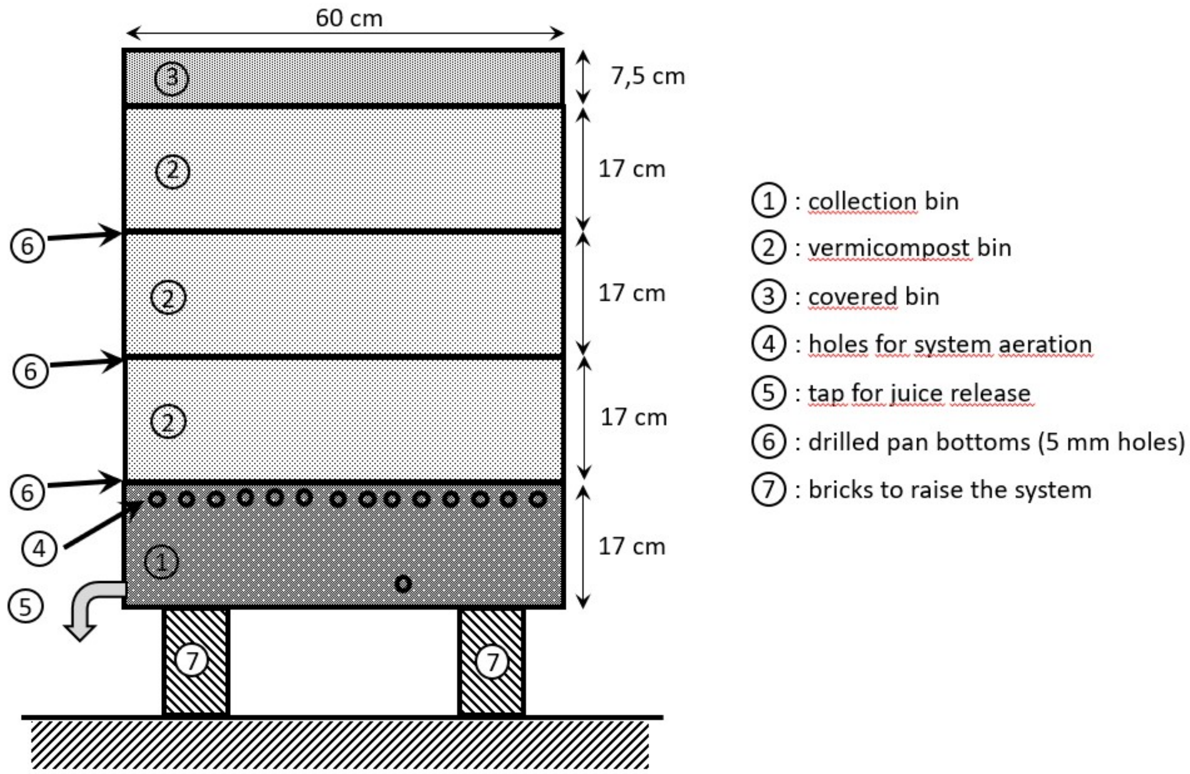
5.6 Characteristics of vermicompost

Compared with traditional compost, vermicompost is, depending on the inputs used, rich in fertilizing elements, particularly in mineral nitrogen assimilable by plants (mainly nitrate). This is due, on the one hand, to the inputs used (raw materials low in lignin and rich in fertilizing elements) and, on the other, to the fact that vermicomposting does not include a thermal phase, during which part of the mineral nitrogen is lost in gaseous form (ammonia).

Vermicompost should therefore be used as an organic fertilizer, and in moderate quantities to avoid over-fertilization and fertilizer losses through leaching.

Vermicompost is also characterized by high microbiological activity, which has a positive influence on soil fertility and plant growth.

The most important point to bear in mind is the hygienic aspect of vermicompost. Unlike traditional composting, vermicompost does not go through a thermal phase, so the destruction of weeds or pathogens is not 100% guaranteed. That's why it's important to choose inputs that don't pose any problems in this respect. It is also possible to subject inputs to a short thermal phase (pre-composting of 10 to 15 days) before introducing them into the vermicomposting system, which will certainly entail a loss of nitrogen, but will guarantee a final product that is beyond reproach from a hygiene point of view.



Example of a home vermicomposting system with 3 compost bins. When the top bin is filled with fresh material, the bottom bin, which contains the mature vermicompost, can be emptied and returned to the top of the system.

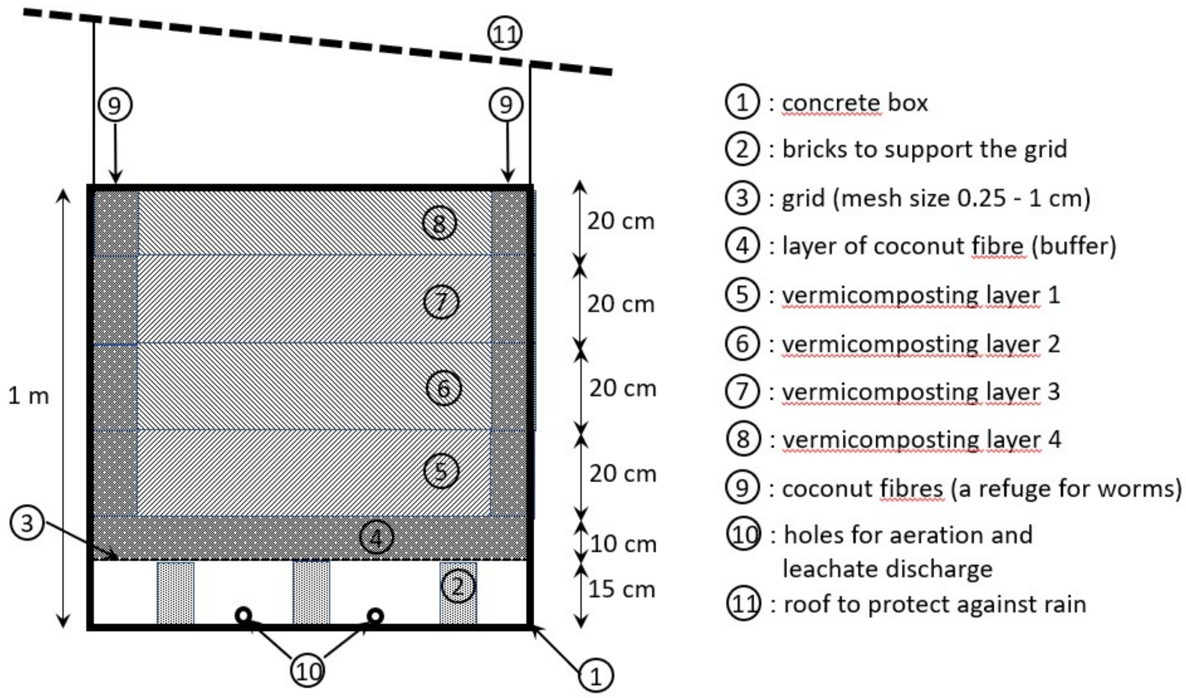
5.7 Vermicompost tea

Vermicompost can also be used to produce compost tea, which fortifies plants with nutrients and beneficial microbes.

The production of vermicompost tea is relatively simple. The compost is placed in a permeable bag (e.g. gauze cloth) and placed in water (e.g. rain or stream water) for one or two days. This water can also be aerated during incubation using a small aquarium pump, but this is not absolutely essential. If the vermicompost is of impeccable quality and contains no pathogens, the addition of a few simple sugars (e.g. molasses) can encourage the growth of useful micro-organisms in the soil.

Compost tea is usually diluted (1:4) before use. It can then be used to water plants or spray leaves.

It's a good idea to do your own tests with the vermicompost tea you've produced, to optimize its use in the best possible conditions.



Example of a vermicomposting system in boxes. Fresh material is added in 20 cm layers. Due to the reduced volume of the material, a 20 cm layer of fresh material can actually be added 6 to 7 times. When the top layer is full, the top 30 to 40 cm of the box (containing the worms) is transferred to a new box, the remaining material constituting the mature vermicompost that can be harvested.

6. Planning and building a compost bin

The use of quality composts improves and maintains soil fertility and provides optimum nutrition for plants. It helps to increase the quantity of vegetable production, as well as the quality of the produce. Composts improve soil structure and water retention, as well as the disease resistance of certain plants, and are therefore important to growers' success.

However, these positive effects of compost can only be achieved if..:

- impeccable product quality
- the choice of compost used is appropriate for the uses and effects sought
- the use strategy is correct

Depending on the raw materials used and the way the process is managed, not all composts have the same characteristics and therefore the same effect on soil and plants. What's more, each use of compost has different requirements. It is crucial to choose the right compost and application concept for the specific needs of the particular situation (crop, soil characteristics, application period, desired effects, etc.).

A good relationship between compost producer and user is the key to successful implementation of compost in agricultural systems.

6.1 Planning a compost plant

Good planning of a composting facility ensures that you get the right facility for the right situation and the right objectives. As every situation is different, every composting facility has its own characteristics. Even if the general basis of planning is universal. The planning of a composting facility is not limited to technical aspects, but must also include the general concept of its management and local socio-economic aspects.

The various aspects to be taken into account when planning a composting facility are as follows:

- Organic waste to be processed
- Outlets for the composts produced
- Available space
- Geographical location
- Available resources (machines, human resources, financial capacity)
- Country regulations

When planning a composting facility, it is often necessary to make compromises in order to best meet different requirements. It therefore makes sense to study and quantify several alternatives before making a decision. In addition, it's advisable to plan a composting facility concept that can be optimized, extended or redesigned at a later date, in order to adapt to changing circumstances.

a. Organic waste to be processed

The first essential point to clarify is which organic residues (materials) are available or can be organized for composting. The aim is to produce starting mixtures that are perfectly suited to composting. This means a C:N ratio of between 30 and 40 and a mix structure that allows air to circulate without being too loose. If the materials available are too one-sided (for example, one type of material accounts for around 90%), it may be necessary to organize other inputs to balance the starting mix. The starting mix finally available will also influence the choice of composting system.

The planning of a composting facility should be focused on a full year. Indeed, the arrival of different inputs often varies in quantity over the course of the year. Some, like wood products, can be stored for long periods, while others, with no structure (like vegetable waste), need to be processed as quickly as possible. Stockpiles of storable waste must therefore be created so that suitable starting mixes can be prepared as soon as the unstructured material arrives at the composting facility.

To plan and carry out these mixes, you need to know which materials are available at which times of the year. To do this, a table must be created showing the different materials that may be available per quarter.

Quantification of available biological waste

List the different types of organic material you wish to compost, indicating the period of availability during the year and the quantity of material available at any given time. This table serves as a basis for planning a specific mix of materials well-suited to making good compost.

Quantification of available organic waste (estimate in tons of fresh mass) Indicate all possible organic waste, even if its treatment is not currently planned.									
Material[1]	Origin	Moisture[2]	Structure[3]	Density [ton/m^3]	Available quantity (tons of fresh produce/quarter)				Remarks
					Jan-March	April-June	July-Sept.	Oct-Dec.	

[1]Examples: Cattle manure, chicken manure, vegetable waste, palm leaves, horticultural waste, community collection tour, etc.

[2]If possible, indicate the dry content (in % of fresh mass), otherwise estimate the moisture content of the product: dry, moderately moist, moist, wet, very moist, ...

[3]Assessment of material structure: poor (such as vegetable waste, sawdust), good (such as garden waste, straw manure), high (such as wooden

b. Market opportunities for the compost produced

At the other end of the composting system, when you get the final product, it's important to define the intended uses for the compost produced. If the composts are not used by the composting plant itself, the product may be sold. For better sales, it's a good idea to carry out a brief study of the commercial potential of composts (or products derived from them).

This is because, depending on the intended use, the characteristics of the composts required are not the same (degree of maturation, sieve granulometry, nutrient content, addition of other components, etc.). In order to do this, another table must be drawn up for products leaving the composting plant.

Outlets for compost produced.

Sale market[1]	Required maturity[2]	Mesh width [mm]	Addition of further components[3]	Density [tons / m^3]	Market potential [m^3]				Remarks
					Jan-March	April-June	July-Sept.	Oct-Dec.	

[1]Examples: Arable farming, field vegetables, greenhouse vegetables, private gardeners, soil mixture, ...
[2]Degree of maturity of the compost: fresh (just after the heat phase, medium-ripe mature
[3]Examples of other components: Peat, coconut fibers, sand, perlite, clay, ...

c. Choosing and planning a composting system

The types of inputs available and the qualities of the composts produced certainly play an important role in the choice of composting systems. However, other factors will also play an important role: the total annual quantity of organic waste processed, the geographical location of the composting facility (e.g. proximity to housing), water resources, available financial and human resources, etc.

In general, you need between 0.8 and 1.5 m^2 per ton of organic waste processed per year. When the quantity of organic waste processed is low (1'000-2'000 tons per year), the space required per ton is greater (due to the surface area required for machine traffic and operations such as shredding and screening). Similarly, the more elaborate the products manufactured (such as potting soil), the greater the demand for space.

The different types of composting systems, with their possibilities and limitations, are presented in Chapter 1.1.

In many cases, a composting system with small compost windrows is well suited. It's a highly flexible system that can be adapted, through appropriate process management, to different starting mixes. Depending on the size of the system, input quantities ranging from 2,000 to over 30,000 tons per year can be processed. As the situation evolves, such a plant can be expanded without too many problems.

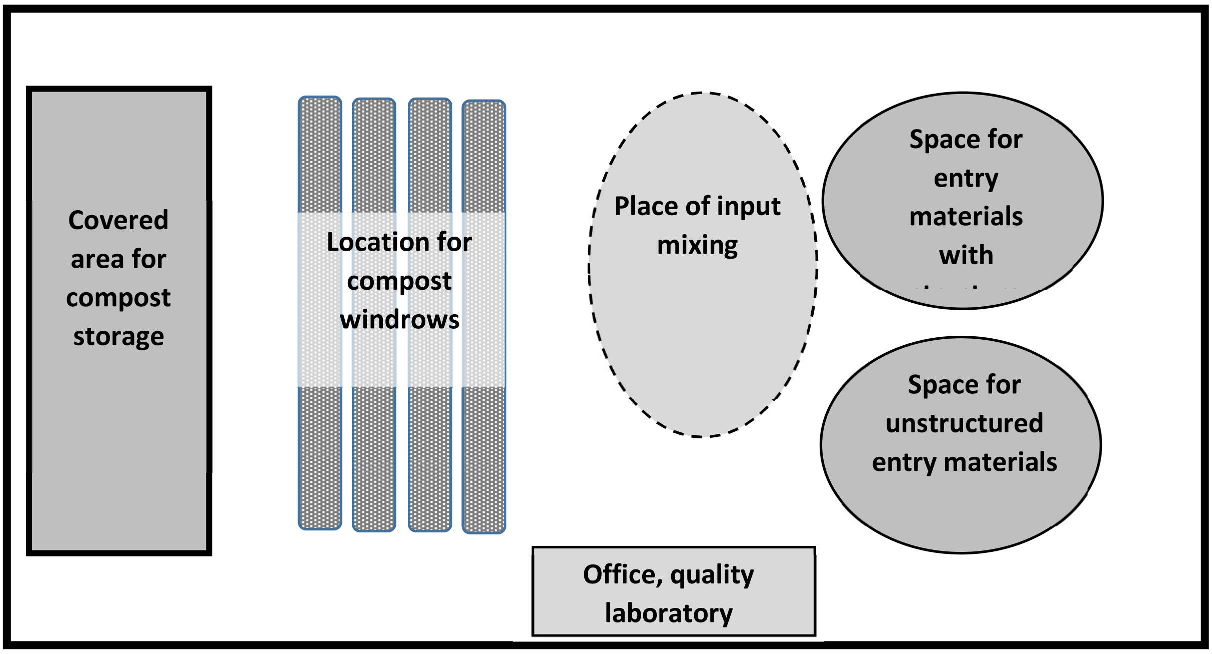
We'll take this system as an example for the planning of a composting plant, and consider an input quantity of 5,000 tons/year.

To process around 5000 tons of organic waste per year (including storage space for the compost produced), a surface area of around 7500 m^2 is required. This surface must be hard to facilitate the composting process and limit environmental risks.

A composting facility must include the following components:

1. Space for organic waste disposal. This space must be divided to allow separate treatment of the various inputs. As a minimum, there should be a clear separation between structural materials (such as woody materials), which can be stored for a long period, and non-structural waste, which must be processed in the short term.
2. Space for making starting mixes. This is where structured inputs are shredded and mixed with unstructured materials.
3. Space for windrows. This is where the actual composting takes place. This part of the square should have a 2-3% slope parallel to the windrows, so that rainwater can run off in the event of heavy rainfall. If technically and financially feasible, covering the windrow area would be a great advantage for managing the process and would also allow rainwater falling on the roof to be collected, which can be used to regulate the humidity of the windrows.
4. A covered storage area for the compost produced. These mature composts are highly sensitive to the vagaries of the weather and must therefore be protected in order to guarantee the quality of the composts until they are used. Between the windrows and the compost storage area, there must be a sufficiently large surface area for sieving the composts.
5. An office to house a small laboratory is needed to manage the composting plant's operations and carry out the work required to guarantee product quality. Depending on the waste collection concept, a scale may also be required.

A schematic diagram of a composting facility is shown on the figure below. Of course, precise site planning can only be carried out when the exact situation is known and assessed.



Schematic diagram of a composting facility.

d. Infrastructure requirements

In addition to the construction of the composting site itself, described in the previous chapter, various other infrastructures are required for composting. In this document, we won't go into detail about the "small equipment" required, such as thermometers or laboratory infrastructures. Only the more expensive machinery required for plants processing several dozen tons of organic waste per year is discussed here.

The three most important machines are the loader, the shredder and the brewer. The second priority (depending on the intended outlets for composts and processed inputs) is a screening machine, and the final priority is a machine for packaging the finished products.

Loader

A loader is needed to handle the processed materials. A front-mounted tractor is probably the most appropriate solution to start with, as this tractor could also be used to stir compost heaps with a tractor-drawn mixer. However, the tractor must have sufficient power to do the job.

Shredder

A shredder is needed to defibrate structural materials such as tree or shrub branches. An important point is that this machine does not cut the products but crushes them. Indeed, only well-defibrated woody products can be attacked by microorganisms during composting. The size of the shredder must be adapted to the quantity of material processed. Depending on the situation, it is also possible to hire the services of a specialized company to carry out the work.

Example of a tractor with front-end and loaders.

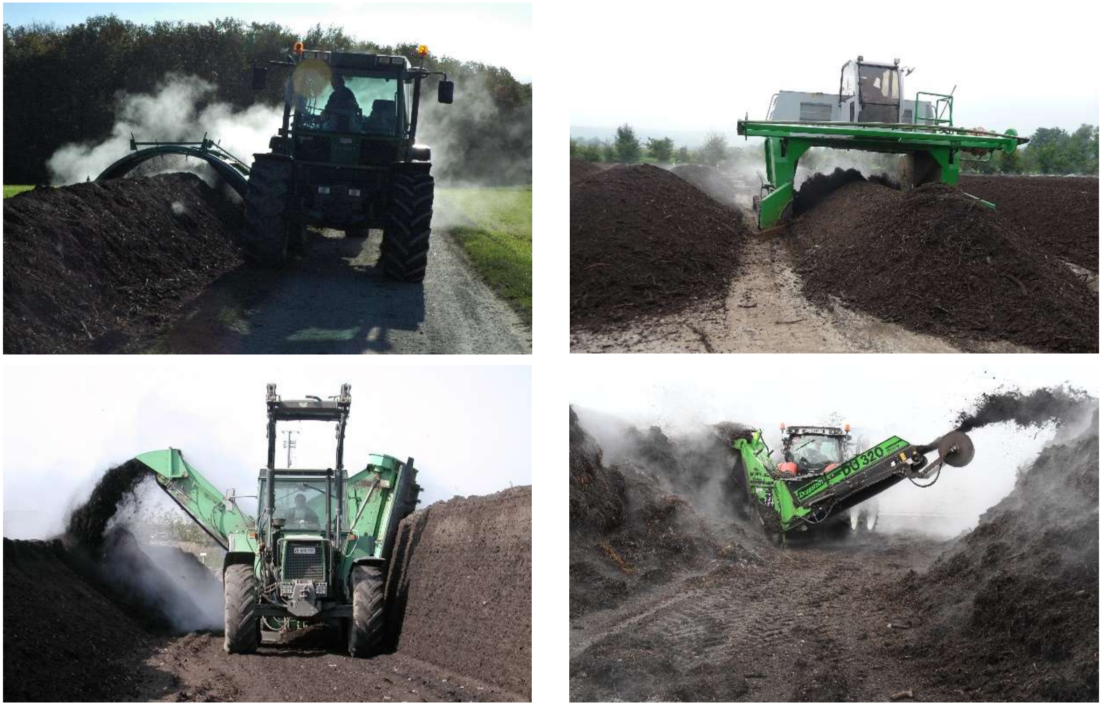
Examples of shredders for composting plants.

<u>Compost turner</u>

To produce quality compost, a compost turner is an important investment. To begin with, a tractor-pulled turner is certainly an advantageous solution. Choose a model capable of turning windrows up to 2 meters high. It's also important, when choosing this machine, to find out what your requirements are in terms of tractor questioning (these two machines need to work together). It is also advantageous if this machine has a system for placing and delivering the geotextile used to cover the compost windrows (if the composting area is not covered). The disadvantage of a towed windrower is that it requires a larger composting area, as every two windrows an empty space must be left to allow the tractor to pass.

It is of course possible to use a self-propelled agitator, but this is much more expensive. It does, however, save space on the composting site.

If the purchase of a compost shaker is not possible at the start of the project, the compost can be turned using a loader, taking care to break up the compost clumps during this process. However, the quality of the work done with a loader never reaches that of the work done with a real compost turner, and is also more labor-intensive.



Example of a tractor-pulled and a self-propelled mixing machine

Screening machine

An artisanal system is possible. However, drum or star sieves are available in a variety of sizes, which can be selected according to the dimensions of the planned composting plant. Mesh size should also be chosen according to the final products to be marketed.

The following factors should be considered when selecting machines:

- Sizing the machine according to the quantity of material to be processed
- Choose proven technology
- Machine quality and sturdiness
- After-sales service (including parts availability) in the country
- Machine price (including transport)
    - It is advisable, if possible, to test the machine before purchase. This is particularly recommended for shredders, to see for yourself the results obtained (quality of defibration, machine adjustability (size of shredder), hourly performance of the machine, etc.).

Examples of screening machines: handmade sieves (top left), star sieves (top right) and rotary drum sieves (bottom).

e. Operating documents

Operating documents are particularly important aids for composting plants. They actively contribute to the production of consistent quality products and the optimization of plant processes. They are proof of quality for both the plant manager and the compost buyer.

The most important documents for managing a composting facility are the register of organic waste delivered, the register of outgoing products and, above all, the process control protocol. The latter is essential for optimizing the management of the process itself.

The process control protocol describes the core activity of a composting facility. It forms the basis for composting management and quality assurance. It must be completed for each batch. For this reason, batches must be clearly numbered and tracked from the moment they are set up to the moment the compost is sold (see chapter 3.3.e).

7. Composting experiments

Testing is an important element in optimizing composting processes and the use of the compost produced. In the context of composting, there are two main levels of testing to consider:

- trials to optimize composting processes
- trials to optimize the use of the compost produced.

In addition to the optimization objective, the trials also have an important role to play in communicating with the various parties involved in the system, from municipalities and composters to farmers and citizens.

7.1 Composting process optimization trials

In order to optimize the composting process, various trials can be proposed. Based on the results of these tests, further trials can be planned at a later date. Some examples of trials are presented here. They can be carried out in a test composter or on a farm equipped with a windrow composting system.

a. Example 1: Optimizing raw materials management

The different types of raw materials present must be mixed to obtain an optimum C:N ratio and a structure suitable for the composting process. It can be expected that carbon-rich materials will probably not use up much nitrogen at the start of the process, and that excess nitrogen will be lost in the form of ammonia gases during the first phase of the process. One way of reducing nitrogen losses could be to add only part of the nitrogen-rich material to the mixture at the start of the process, and the rest three or three weeks later, when the carbon-rich material is already partially degraded and therefore able to fix nitrogen.

The questions to be answered in this essay are as follows:

- Can the composting process be improved by optimizing raw materials management?
- Can nitrogen losses be reduced by optimizing raw materials management?
- Can the quality of the compost produced be improved by optimizing raw materials management?

Two treatments can be compared:

- T1: Starting mix with all materials mixed at the beginning of the process. No addition of other materials during the rest of the process.
- T2: Starting mixture with only half the amount of nitrogen-rich material at the beginning of the process. After 3 weeks, add the second half of the nitrogen-rich material.

b. Example 2: Improving the composting process through inoculation with specific micro-organisms

The inoculation of specific micro-organisms, such as those that break down cellulose or lignin, or those that have antagonistic effects on pathogens, could potentially improve the composting process and the quality of the finished product. However, the timing of the addition of the various micro-organisms could influence their positive effect. Microorganisms involved in the composting process itself and which are resistant to high temperatures might be expected to be more beneficial when applied early in the process, whereas, for example, antagonists with low heat resistance would be more beneficial when added to compost during the maturation phase. Tests should be carried out to optimize the use of the specific micro-organisms chosen.

The questions to be answered in this essay are as follows:

- Can the inoculation of specific micro-organisms improve the composting process and the quality of the compost produced?
- When is the best time in the process to add the selected micro-organisms?
- Can disease suppression be improved by adding selected antagonists?

Three treatments can be compared for a micro-organism or a complex of micro-organisms:

- T1: Composting of starting mixture without addition of specific micro-organisms.
- T2: Composting of the starting mixture with the addition of specific micro-organisms at the beginning of the process.
- T3: Composting of the starting mixture with the addition of specific micro-organisms during the curing phase.

c. Example 3: Optimizing the turning interval

Turning the compost is an important operation to ensure a good composting process. However, the turning interval must be adapted to the composting system and the raw material being composted. If windrows are turned too often, nitrogen (ammonia) and moisture are lost. If the compost windrow is not turned often enough, the homogeneity of the process can no longer be ensured, and there is a risk of anaerobic sites appearing in the windrow, which can have a negative influence on compost quality.

The questions to be answered in this essay are as follows:

- What is the optimum windrow turning intensity for:
  - obtain high-quality compost,
  - avoid nitrogen losses during the composting process, and
  - avoid unnecessary work and costs

For example, three treatments can be compared:

- T1: Windrows with turning interval: 3 days.
- T2: Windrows with a turning interval of 1 week.
- T3: Windrows with a 2-week turning interval.

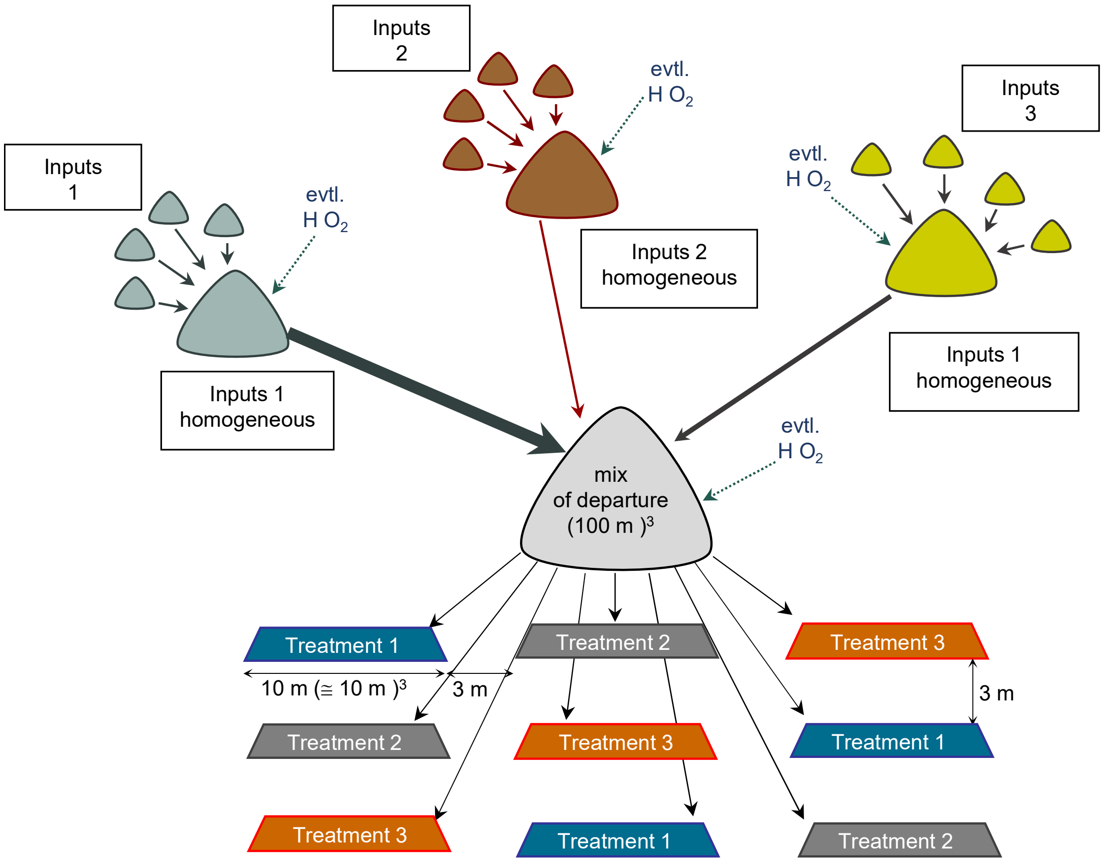
7.2 Methodology for conducting composting trials

In general, simple practical tests can be carried out without repetition to get to the bottom of the question asked. If we want to obtain more precise answers to our questions, we prefer exact tests with repetition.

In all cases, it is preferable to modify only one parameter between the variants tested, otherwise it is hardly possible to assess the cause of the differences obtained. To obtain relevant results, it is important to work with precision and to document all operations carried out and all measurements and observations made.

An important point in composting trials is pile size. This has a major influence on the composting process, due to changes in heap temperature and aeration. For example, results obtained with 50-liter piles cannot be exported to 50-m piles$^{3.}$ For the tests to be relevant to practical composting, a minimum of 3 to 5 m^3 per test heap should be considered, and later, the most promising variants should be retested under the practical conditions encountered in the composting facility in question.

If the starting mixture is the same for all treatments, a homogeneous mixture must be prepared in sufficient quantity for all treatments (+ approx. 10% reserve), then distributed between the different treatments. Be careful when mixing: 1 m^3 of product A + 1 m^3 of product B does not give 2 m$^{3.}$ This is because the finer material can penetrate the pores of the coarser material and "disappear". This is typically the case when clay or fine biochar is added.



Exact composting test with the same starting mix for all treatments

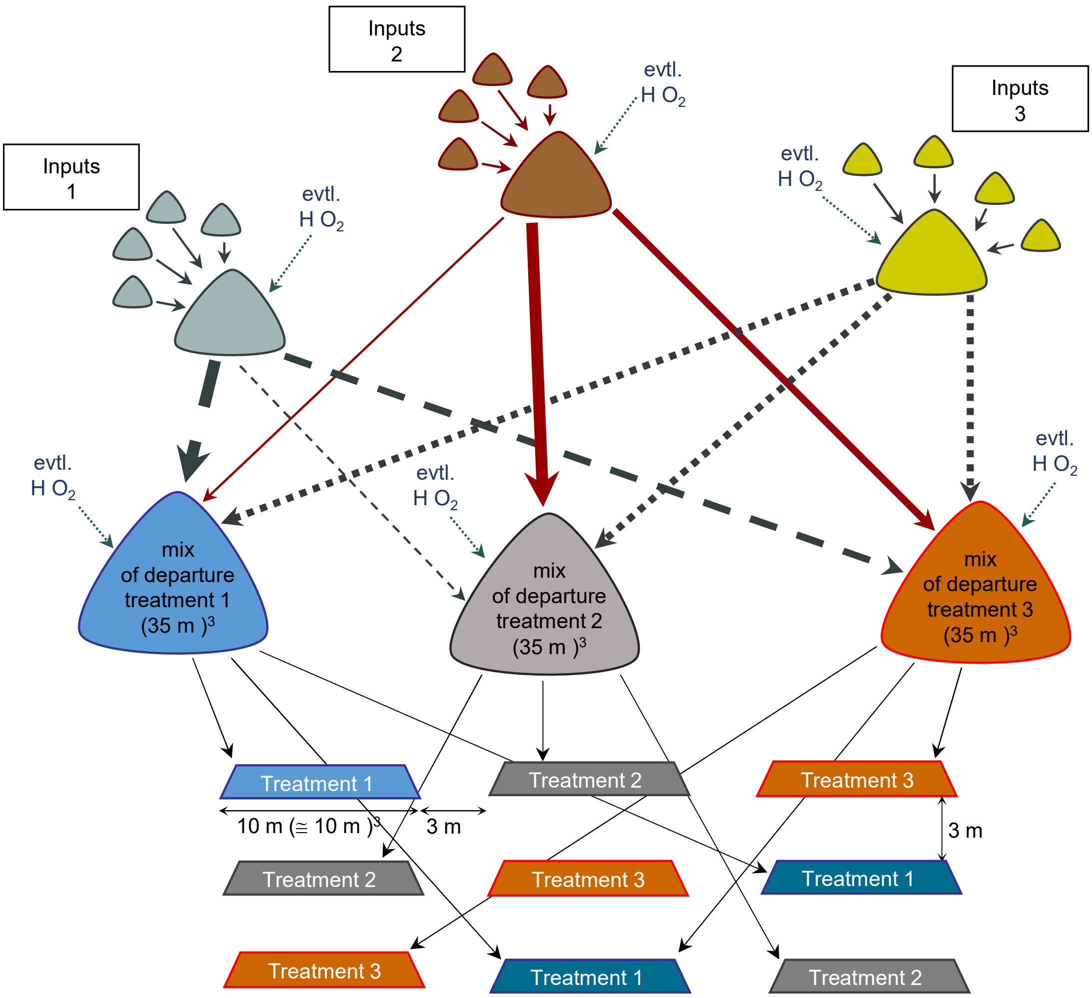
If different mixtures are to be compared, a homogeneous mixture per treatment must be prepared for all the replicates, then distributed between the different replicates.

The composting process must be intensively monitored, using precise protocols, particularly during the first ten weeks of the process.

Humidity levels must be monitored throughout the process.

Compost samples for analysis should normally be taken at least twice during the process: at the end of the warm phase (when the temperature clearly begins to drop) and when the compost has reached maturity (the temperature hardly rises at all in the two days following compost turning). The most effective method is to take samples immediately after turning the compost. To obtain a homogeneous, representative sample, 20 sub-samples of 500 to 1,000 ml are taken from different parts of the compost heap and thoroughly mixed. The required quantity of compost is then taken from this mixture.

Analyses should be carried out on site as soon as possible after sampling. If same-day analyses are not possible, samples should be stored at 4 ˚C until analysis can be performed.



Exact composting test with different starting mixes

View of a composting process optimization trial as samples are taken for analysis.

7.3 Tests to optimize the use of compost produced

Before starting an experiment using compost, the specific question to be answered should be clearly defined, as it will influence the design and organization of the trial: compost's influence on soil structure, compost's fertilizing effect, plant disease control, etc.

It is also necessary to define whether the trial has a demonstration purpose or is intended to produce data of relevant statistical value.

In compost application trials, a distinction can also be made between pot trials (which make it possible to test a relatively large number of variants over small areas and with a reasonable investment in terms of labor and costs) and pot trials (which make it possible to test a relatively large number of variants over small areas and with a reasonable investment in terms of labor and costs).

In compost application trials, a distinction can also be made between pot trials (which allow a relatively large number of variants to be tested over small areas, with a reasonable investment in terms of labor and costs) and field trials (which have good practical relevance, but do not allow a large number of variants to be tested, and require a great deal of labor and care).

a. General conditions for carrying out composting experiments in the field

The site on which the experiment is to be carried out must be homogeneous. This means, for example, that the site must be subject to disease attack if the suppressive effect of composts is to be studied.

The soil in which the experiment is carried out must also be analyzed (soil type, texture, organic matter content, N, P, K, Mg, Ca, etc.). The composts used must also be well characterized so that results from different experiments can be compared.

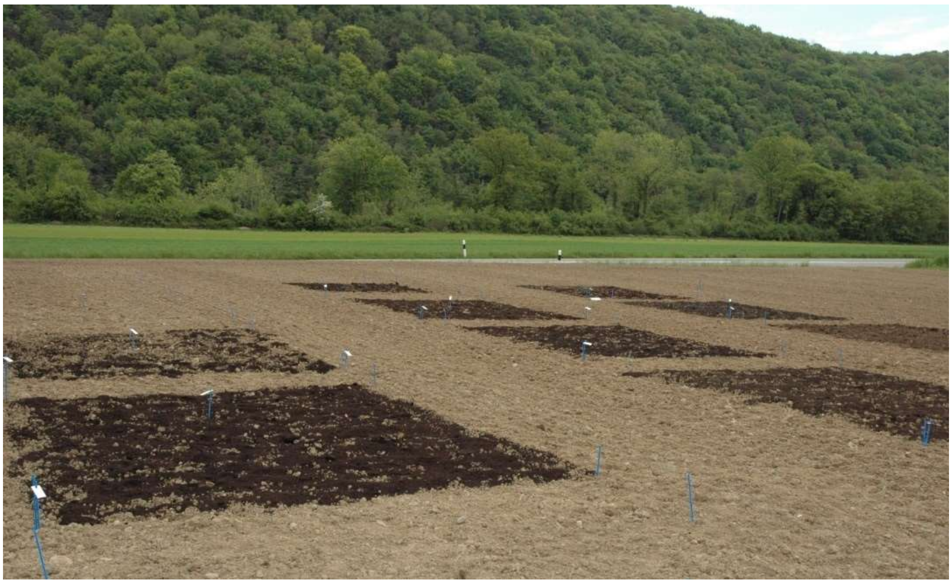
If the aim is not just to answer questions about fertilization, it's important to have a standard treatment (a N, P, K, Mg control) in addition to an untreated reference plot. For other questions, the control plots should generally be fertilized, with commercial fertilizers, to the same level as the fertilizers supplied by the compost.

b. Design of field experiments

For single-season experiments, a standard design with four replicates can be used.

In experiments lasting several years (e.g. to assess the effect of compost on soil structure), plots need to be larger to avoid mixing soils from different treatments. Buffer zones, in which no measurements are taken, are more important than in short-term experiments. For experiments lasting several years, soil samples must be taken from all plots and analyzed before work begins.

For demonstration experiments, larger, non-replicated plots are generally used (for example, half the field with compost, half the field with a reference fertilizer or with the farmer's usual practice).



View of an application trial comparing different composts.

c. Pot tests

Pot trials enable us to test a large number of variants, including extreme variants of no practical importance, in order to study the limits and risks of the composts produced.

These trials are also good communication and training tools for the people involved and the farmers. As shown in figure 3.5, we can demonstrate to staff and farmers that there is an optimum in the quantities of composts used, and that larger quantities are detrimental to plants (overfertilization, salinity, etc.).

Pot demonstration experiment on the influence of compost application on cabbage growth (by TakaTakaSolutions, Nairobi, Kenya).

As with field trials, it is important that the soil or substrate for the base mix is homogeneous throughout the trial. Compost or other products (e.g. commercial fertilizers) are then added to this base mix.

To be able to evaluate the results, a minimum of 6 pots per variant must be used.

View of an experiment designed to test the effect of different composts on plant growth (REPIC project in Côte d'Ivoire).
Left: trials in pots. Right: trials in flowerbeds.

d. Documentation and use of plant experiments

To be useful, tests must be well documented and precise protocols carefully followed. Photographic documentation (with appropriate labelling of photos) of trials is also strongly recommended. This applies equally to demonstration trials and trials that didn't work. In fact, evaluating failures helps us to make progress in optimizing composts and their uses.

Plant trials are very labor-intensive, so it's important to prepare and monitor them properly, in order to amortize the energy used to carry them out. To be successful, a trial must be carefully planned: choice of field or land according to the objectives pursued, choice of variants (including choice of controls), choice of crops, seeds or plants, measures to be taken to protect the trial (e.g. nets to protect the trial from insects or birds), etc.

As a minimum, the following points must be documented in the protocol:

- Precise schedule of operations (date of soil preparation, date of sowing or planting, date of inspections, dates of watering or other actions carried out, etc.).
- Test location
- Persons responsible for and involved in the trial
- Type of soil or substrate used
- Trial size (surface area, pot size, number of pots, etc.)
- Test plan (especially for field tests)
- Varieties tested
- Plants (variety, origin of seeds or seedlings)
- Number of plants per m2 or per pot
- General comments made during the trial
- Measurement data (plant height, weight, disease assessment, mortality, etc.)

In addition to providing data for optimizing composting operations and the use of the composts produced, the trials are excellent communication and training tools for the players involved (waste suppliers, plant personnel, municipalities, etc.) and for potential users of the composts produced (farmers, agricultural advisors, cooperatives, private individuals, etc.).

Various information activities, including trial visits and discussions of the various results, provide an important forum for exchange between the various players, improving mutual understanding of the partners' possibilities, limitations and wishes, and thus helping to optimize the system as a whole.

The results obtained must also be disseminated. Various means are available for this purpose: posters, data sheets, presentations, videos, newspaper articles, etc.).

8. Using compost

The use of quality composts improves and maintains soil fertility and provides optimum nutrition for plants. It increases the quantity and quality of vegetable production. Compost improves soil structure and water retention, as well as the disease resistance of certain plants, and is therefore important to growers' success.

However, these positive effects of compost can only be achieved if:

- \- impeccable product quality
- \- the choice of compost used is consistent with its intended use and effects
- \- the use strategy is correct.

Depending on the raw materials used and how the process is managed, not all composts have the same characteristics and therefore the same effect on soil and plants. What's more, each use of compost has different requirements. It's essential to choose the right compost and application concept for the specific needs of the particular situation (crop, soil characteristics, application period, desired effects, etc.).

A good relationship between compost producer and user is the key to successful implementation of compost in agricultural systems.

8.1 Defining needs according to objectives

To develop a strategy for selecting and using compost, you first need to define the objectives and conditions of use. To do this, you need to ask yourself the following questions:

- main objective: crop fertilization or soil fertility improvement (humus content, structure, etc.)
- target crop for compost use
- for perennial crops: application at the time of planting or maintenance of a yielding plantation.

If the primary objective is to fertilize crops, it's best to choose a compost rich in available fertilizing elements (particularly nitrogen). This can be vermicompost or traditional compost containing a significant amount of manure.

If the primary objective is to improve soil quality, you should choose a relatively mature compost containing a significant amount of woody matter (such as green waste compost to which biochar has been added).

The target crop and the timing of compost application (at planting or as part of crop maintenance) are particularly important in defining the quantities of compost to be used, so that they correspond to the plant's needs. Over-fertilizing crops can be just as detrimental to their growth as under-fertilizing, and can also have harmful effects on the environment (nutrient leaching, greenhouse gas emissions such as laughing gas, etc.).

8.2 Assessing compost quality

To be able to choose the right compost for the right purpose and define an appropriate strategy for its use, it is essential to correctly assess the quality of available composts. This also provides a basis for discussion between compost producer and user.
First of all, observing composts with your own senses (sight, smell, touch) gives you an initial idea of the basic quality of the products (see chapter 4.5.b).
A study of the processing protocols also ensures that the compost has benefited from the conditions required to be hygienically irreproachable (chapter 3.3.e).
The next step is chemical analysis of the compost. Of course, the first thing to check is that the quantities of pollutants (heavy metals, plastics, etc.) do not exceed legal limits. Analysis of total fertilizing elements, carried out by an accredited external laboratory, is then essential for planning fertilization balances and defining the quantities of products to be used (see chapter 4.1 and 4.3).
Finally, the mineral nitrogen content (N_{min}) of composts enables us to assess their degree of maturation, and also gives an indication of compost quality. A compost with an N_{min}/N_{tot} ratio of less than 5% will have little short-term nitrogen effect, whereas a compost with an $N(min)/N_{(tot)}$ ratio of over 10% will. On the other hand, compost containing mainly ammonium (NH_4-N) as mineral nitrogen is biologically young, whereas mature compost contains mainly nitrate (NO_3-N). The presence of large quantities of nitrite (NO_2-N) is a sign of a lack of oxygen during the ripening or storage phase, leading to compost of inferior quality which may even be toxic to plants (see chapter 4.5c).

8.3 Assessment of fertilization balance

Each plant has different fertilizer requirements. This is why it is necessary to adapt the amount of compost applied to the crop. As the total nutrient content of composts can vary considerably, it is important to make these calculations using the analyses of the intended compost, and not to rely on average values found in the literature.
Local agricultural advisors can define crop fertilizer requirements according to climatic conditions and soil types. Information from the literature can also be useful in this respect.
As far as nitrogen is concerned, only 10% of total nitrogen is normally considered in the nutrient balance, the rest being linked to organic matter and not available to plants in the short term.
Vermicompost and digestate contain more mineral nitrogen than traditional compost. This is why 20% of total nitrogen can be taken into account in the fertilization balance.
When calculating the amount of compost to apply to the crop, the nutrient that first covers the plant's needs is the determining factor. Targeted applications of commercial fertilizers should then be made to cover the needs of other nutrients, if necessary (see chapter 4.3).
Local agricultural advisors can calculate the needs of plants under local conditions and develop a fertilization concept based on the use of compost. Practical trials are used to optimize and validate these concepts (see chapter 7.7).

8.4 Practical use of composts in the field

Compost provides crops with fertilizers (macro- and micro-nutrients), but its effect as a soil improver is at least as important. It provides stabilized organic matter in the soil, which improves soil structure and water-holding capacity, reduces erosion, positively influences pH levels and activates soil biological activity. Compost can also have a suppressive effect on soil-borne plant diseases.

However, to develop these positive effects, correct application of compost is essential. After spreading, compost must be quickly incorporated into the top few centimeters of soil. If it remains on the surface, it can dry out, resulting in a loss of fertilizing elements and inactivation of its positive biological activity.

Compost can be spread manually or by machine. Care must be taken to ensure that the compost is spread evenly over the entire crop.

Depending on the crop, compost can be spread over the entire field surface (e.g. cereals or corn) or concentrated on the planting line or mounds (e.g. market garden crops).

When planting (e.g. tomatoes or fruit trees), compost can be placed in the planting hole. This is more effective than putting it around the plants after planting. However, care must be taken not to put pure compost in the planting hole, but first to dilute it by mixing it with the soil in the field (e.g. $^{1}/_{3}$ compost + $^{2}/_{3}$ soil). Pure compost is too rich for plant roots, which may be damaged or have their growth slowed down.

For short-lived crops (e.g. vegetables), application before sowing or planting is appropriate.

For perennial crops, we recommend repeated application, e.g. every two or three years. For optimum effect, compost should be incorporated into the soil surface (e.g. by scraping) each time. Irrigating the crop after composting enables it to integrate better into the soil and develop its beneficial effects.

9. Conclusions

Recycling organic residues is an important activity for the environment and the climate. It can recycle important fertilizing elements for plants, ensuring soil fertility and plant health. What's more, proper management of this recycling helps limit greenhouse gas emissions (methane, laughing gas) produced by these poorly managed residues.

However, to achieve these positive results, the management of organic residues requires optimal management of the recycling process, from the collection of organic residues to the use of the resulting products.

There are a number of ways to recycle organic waste: methanization, composting, vermicomposting, pyrolysis, etc. All these processes should be seen as complementary rather than competitive. All these processes should be seen as complementary rather than competitive. The choice of concept depends on a number of factors: inputs to be processed, product outlets, infrastructure, available finance and manpower, etc.

Composting has a privileged place in this constellation, not least because of its flexibility: it can be carried out with little infrastructure and investment, can process a wide variety of organic residues and, if carried out optimally, can have very positive effects on soil fertility and plant health, and so on.

Understanding composting processes and their possible effects on crops is paramount to the successful management of composting operations. The aim of this document is to humbly offer a few elements that can help to achieve a recycling of organic remains that contributes to the sustainable management of our environment.

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FiBL

CH-Frick, May 2025

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Annex 1

Chemical analysis of compost

in a field laboratory

Dr. Jacques G. Fuchs, FiBL & Biophyt Ltd

CH-Frick, 24.11.2022

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Annex I

Chemical analysis of compost in a field laboratory

Dr. Jacques G. Fuchs, FiBL, CH-Frick, 24.11.2022

1. Necessary equipment: instruments

- **Shaker** (to perform the compost extracts), with reciprocal motion type or overhead shaker
  - e.g.: Orbital multi-platform shaker, PSU-20i, with Universal platform, with adjustable bars and two fixing levels, 345×430 mm (www.vwr.com)
  - Possibility to build your own shaker (overhead shaker)

- **Oven** with circulating air
  - to dry compost by 105°C during 24 hours

- **Funnel rack** (filtration bench): own construction

- **Precision balance** (weighing range 1000 g, readability 0.01 g)

- **Reflectometer RQflex** (to measure NH4, NO2 and NO3) (www.vwr.com, article number: 1.16970.0001)

- **<u>pH meter</u>**

- **<u>Conductivity meter</u>** (to measure salinity of compost)

2. Necessary equipment: glassware

- **<u>Aluminium trays</u>**, for determination of the dry substance
  - 10 trays à 500 ml

- **<u>Plastic wide neck bottles for extraction</u>**, 1000 ml, with cap
  - 12 bottles (allows the extraction of 6 compost samples in parallel) (two extracting agents)

- **<u>Plastic wide neck bottles for filtration</u>**, 1000 ml, with cap
  - 12 bottles (allows the filtration of 6 compost samples in parallel) (two extracting agents)

- **<u>Funnel</u>** (upper ⌀ 120 mm, outlet ⌀ 12 mm)
  - 12 funnels (allows the filtration of 6 compost samples in parallel) (two extracting agents)

- **<u>Powder funnel</u>** (upper ⌀ 150 mm)
  - 1 funnels (to fill the compost in the extraction bottles)

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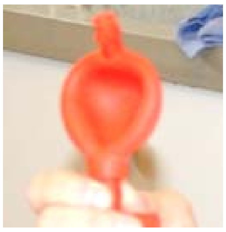
- **<u>Measuring cylinders</u>**, tall, made in PP, transparent
  - 1 cylinder 1'000 ml
  - 1 cylinder 500 ml
  - 1 cylinder 100 ml

- **<u>Griffin beakers,</u>** made in PP, transparent
  - 10 griffin brakers à 100 ml

- **<u>Wash bottle,</u>** 500 ml, made in PP, transparent
  - 2 wash bottles à 500 ml

- **<u>Measuring cylinders</u>**, tall, made in PP, transparent
  - 1 cylinder 1'000 ml
  - 1 cylinder 500 ml
  - 1 cylinder 100 ml

- **<u>Pipetting ball</u>**
  - 1 pipetting ball



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3. Necessary equipment: consumables

- **Standard conductivity,** 1413 µS/cm, to calibrate the electroconductivity meter
- **pH buffer solution**, to calibre the pH meter
  - pH 7,00
  - pH 10.01
- **Folded filters**, type: MN 619 eh1/4, diameter 240 mm
- **demineralised or distilled water**
- **Calcium chloride dehydrate**, $CaCl2 \times 2$ $H2O$ (500 g)
- **Test strips for test method, Reflectoquant®** (www.vwr.com)
  - ammonium: NH4 0.2-7 ppm (www.vwr.com, article number 1.16892.0001)
  - nitrite: NO2 0.5-25 ppm (www.vwr.com, article number 1. 16973.0001)
  - nitrate: NO3 5-225 ppm (www.vwr.com, article number 1.16971.0001)

4. Determination of the dry matter content (DM) of compost

Preliminary remarks

In order to be able to compare the salt content and the mineral nitrogen content correctly, it is useful to relate them to the dry weight of the products. In order to be able to do this, the dry content of the compost must be determined beforehand. DM=dry matter, FM=fresh matter.

4.1. Determine the tare weight

- Weigh empty aluminum trays.
- T = Tara

4.2. Weigh moist compost

- Place approx.. 200 g in the aluminium tray and measure the weight accurately, including the aluminium tray.
- FW: fresh weight

4.3. Drying the compost

- Dry compost in the oven for approx. 24 hours at 105°C (until the weight is constant).

4.4. Weigh the dry compost

- Weigh the digestate or dry compost, including the aluminium tray.
- DW: dry weight

4.5. Result

- DM [% FM] = (DW-T)/(FW-T)*100

5. Production of the water extract, of the $CaCl_2$ extract, and measurement of the pH value

Preliminary remarks

The pH value is measured in the 0.01M $CaCl_2$ extract (10:1) before filtration. The ammonium, nitrite and nitrate contents are analyzed in this extract after filtration of the extracts. Salinity is analyzed in the H_2O extract after its filtration. The extracts must be analyzed immediately. In the worst case, they can be stored for one day in the refrigerator (4°C) or in the freezer.

5.1. Extract H_20

- Fill 500 ml of demineralized or distilled water in one l liter extraction bottle (with the graduated cylinder).
- Weigh about 50 g of the fresh compost. Note the exact weight I the protocol of laboratory.
- Add the compost in the extraction bottle.
  Close the bottle tightly and put it on the shaker. Shake for 60 minutes.

5.2. Extract 0.01 M of $CaCl_2$

- Mix 1.47g $CaCl_2$ x 2 H_2O per liter of demineralized or distilled water (= $CaCl_2$-extraction medium).
- Fill 500 ml of $CaCl_2$-extraction medium in one l liter extraction bottle (with the graduated cylinder).
- Weigh about 50 g of the fresh compost. Note the exact weight I the protocol of laboratory.
- Add the compost in the extraction bottle.
- Close the bottle tightly and put it on the shaker. Shake for 60 minutes.

5.3. Prepare the filters and funnels while the bottles are being shaken,

5.4. pH measurement

- Measure the pH value by immersing the electrode of the pH meter directly in the $CaCl_2$ extract (before filtration). Wait until the value is stable and record it.

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5.5. Filtration

- Carefully pour the extracts into the filter. Filtration can last quite a long time (1 to 2 hours). Periodically add more extract to the filter.

6. Measurements of salinity, NH_4, NO_2 and NO_3 content of composts

Preliminary remarks

These analyses are performed with the extracts of filtered digestates or composts or with dilutions. The extracts must be analyzed immediately. In case of emergency, they can be kept one or two days in the refrigerator (at 4°C) or in the freezer.

6.1. Salinity measurements

- Immerse the electrode of the electro-conductivity meter in the H_2O extract and read off the value.
- The value measured is in mS/cm (=EC) n the extract. It is to be transformed in KCl_{eq}/kg DM with following formula:

Salt content (in KCl_{eq}/kg DM) = EC (in mS/cm)/DM (in % FM)x583.4

6.2. Measurement of NH_4, NO_2 and NO_3 contents with RQ-flex

- A calibration strip is supplied with each package of test strips. Calibrate the RQ-flex with this strip (see also the RQ-flex instructions for use). This calibration must be performed individually for each test and for each new package of test strips.

6.2.1. Dilution of compost extract

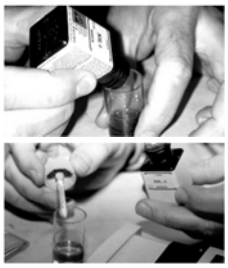
- An extract that is too dark can interfere with the measurements. In this case, or if the nutrient content is too high (RQ-flex gives the result "hi", the extract must be diluted with demineralised or distilled water.
- Dilution 5x: 1 part extract + 4 parts water.
- Dilution 10x: 1 part extract + 9 parts water.

6.2.2. Determination of ammonium content (NH_4-N)

- Fill the test glass to the first line with the 0.01M CaCl2 extract.
- Add 10 drops of the NH4-1 reagent to the test glass and mix with gentle agitation. Attention: Very aggressive

chemical, don't let it touch your skin.

- Add one level blue spoon of the NH4-2 reagent to the test glass and mix with gentle stirring until the reagent is dissolved.



- Check whether the code in the RQ-flex matches the calibration strip.
- Select the NH_4-Test on the RQ-flex once. Press the "Start" button. The test duration is displayed. Immerse the test strip in the extract and press at the same time the "Start" button a second time. The test time is counted down.
- Approximately 20 seconds before the end of the test time, shake the test strip well and insert it into the measuring cell (see also the RQ-flex instructions for use). Read the result. Record the result as well as the dilution of the extract in the laboratory diary.

- The value indicated by the RQ-flex is in ppm NH_4 in the extract. To convert this value into the amount of NH_4-N per kg DM of compost, the following formula is used:
  - A = ppm NH_4 in extract
  - B = compost weight in extract (in g/500 ml)
  - C = Dilution factor
  - D = DM of compost (in % FM) in the $CaCl_2$-Extract

<u>mg NH_4-N / kg DM = A : B x C : D x 50000 : 1.2879</u>

6.2.3. Determination of nitrite content (NO_2-N)

- Check whether the code in the RQ-flex matches the calibration strip.
- Select the NO_2-test. Press the "Start" button on the RQ-flex once. The test duration is displayed. Immerse the test strip in the extract and press at the same time the "Start" button a second time. The test time is counted down.
- After about two seconds, shake the test strip well and insert it into the measuring cell (see also the RQ-flex instructions for use). Read the result. Record the result as well as the dilution of the extract in the laboratory diary.

- The value indicated by the RQ-flex is in ppm NO_2 in the extract. To convert this value into the amount of NO_2-N per kg DM of compost, the following formula is used:
  - A = ppm NO_2 in extract

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- B = compost weight in extract (in g/500 ml)
- C = Dilution factor
- D = DM of compost (in % FM) in the $CaCl_2$-Extract

<u>mg NO_2-N / kg DM = A : B x C : D x 50000 : 3.2844</u>

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6.2.3. Determination of nitrate content (NO_3-N)

- Check whether the code in the RQ-flex matches the calibration strip.
- A nitrite content > 0.5 ppm disturbs the nitrate measurement. If necessary, dilute the extract so that its NO_2 content is below this limit.
- Select the NO_3-test. Press the "Start" button on the RQ-flex once. The test duration is displayed. Immerse the test strip in the extract and press at the same time the "Start" button a second time. The test time is counted down.
- After about twenty seconds, shake the test strip well and insert it into the measuring cell (see also the RQ-flex instructions for use). Read the result. Record the result as well as the dilution of the extract in the laboratory diary.

- The value indicated by the RQ-flex is in ppm NO_3 in the extract. To convert this value into the amount of NO_2-N per kg DM of compost, the following formula is used:
  - A = ppm NO_3 in extract
  - B = compost weight in extract (in g/500 ml)
  - C = Verdünnungsfaktor
  - D = DM of compost (in % FM) in the $CaCl_2$-Extract

mg NO_3-N / kg DM = A : B x C : D x 50000 : 4.4266

7. Interpretation of analyses from NH_4-N, NO_2-N, NO_3-N

Presence of the N_{min} form[1]			Interpretation
NH_4-N	NO_2-N	NO_3-N	
-	-	-	No available N. Mixture too rich in carbon, or all NH_4-N was lost because of lack of moisture. If the compost is carbon rich: risk of nitrogen immobilization in the field. Recommendation: mix some N-rich material to the mixture (digestate, lawn, chicken litter, etc.).
++ / +++	-	-	Young compost (or digestate). Nitrification has still not started. Recommendation: keep the mixture moist enough to avoid NH_4-N losses and allow nitrification.
++/+++	++	+ / ++	Nitrification process starting. Recommendations: keep the mixture sufficiently moist to avoid NH_4-N losses; make sure that the oxygen supply to the mixture is constantly sufficient
+	+/++	++/+++	Nitrification process is progressing. Recommendation: make sure that the oxygen supply to the mixture is constantly sufficient
-	-	++/+++	Nitrification process achieved. Recommendation: make sure that the oxygen supply in the mixture is constantly sufficient Compost is mature and ready to be used.
-	++/+++-	++	Oxygen starvation problem. Recommendation: improved aeration of the compost.

1 -: none (< 10 mg N / kg DM); +: low quantity (10-50 mg N / kg DM); ++: medium quantity (50-200 mg N / kg DM);
+++: high quantity (> 200 mg N / kg DM)

Source: Handbook for Composting and Compost Use in Organic Horticulture, van der Wurff et al., 2016

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8. Interpretation of analyses according to the "Swiss quality guidelines 2022"

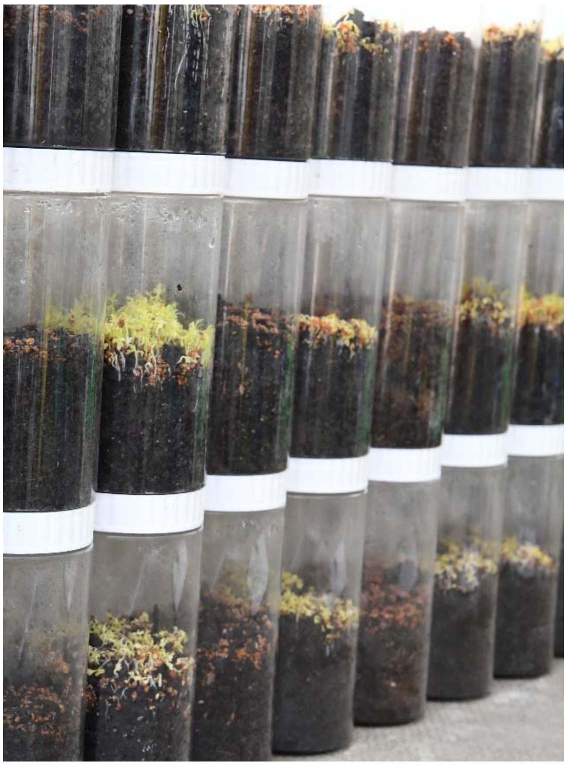
Criteria	Employment in horticulture		
	Compost for field horticulture	Compost for potting soils and home gardening	Compost crops under cover and for substrates
MS (Dry matter)	> 50 %	> 55 %	> 55 %
OM (organic matter)	< 50 %	< 40 %	< 40 %
pH	< 8.2	< 8.0	< 7.8
Particle size	< 25 mm	< 15 mm	< 15 mm
Specific weight	×	×*	×*
Extract color (absorbance 1 cm, extinction 550 nm)	< 0.6	< 0.4	< 0.2
Conductivity	< 2 mS/cm	< 1.3 mS/cm	< 1.0 mS/cm
Salinity	< 20 $gKCl_{(eq)}$ / kg MS	< 13 $gKCl_{(eq)}$ / kg MS	< 10 $gKCl_{(eq)}$ / kg MS
Total nitrogen (N total)	> 10 g/kg DM	> 12 g/kg DM	> 12 g/kg DM
C/N ratio	< 25	< 25	< 20
Ammonium ($N\text{-}NH_{(4)}$))	< 200 mg/kg MS	< 100 mg/kg MS	< 40 mg/kg MS
Nitrate ($N\text{-}NO_{(3)}$))	> 80 mg/kg MS	> 100 mg/kg MS	> 160 mg/kg MS
Nitrite ($N\text{-}NO_{(2)}$))	< 20 mg/kg MS	< 20 mg/kg MS	< 10 mg/kg MS
$N_{min.}$ (ammonium+ nitrate)	> 100 mg/kg MS	> 100 mg/kg MS	> 160 mg/kg MS
$N\text{-}NO_3/N_{min.}$ ratio (only if $N_{min.}$ > 100 mg/kg MS)	> 0.4	> 0.5	> 0.8

× must be indicated

The "Swiss quality guidelines 2022" can be downloaded (in french or german) at www.biophyt.ch/documents/2022_directive-qualite_f.pdf .

Annex 2

Determine the quality of compost using cress tests.

Fuchs, J.G., Weidmann, G. 2018

FiBL, CH-Frick

PRACTICAL TIP NO. 054 from the OK-Net Arable project

www.ok-net-arable.eu

Determine compost quality with watercress tests

Problem

Compost is a valuable recycled fertilizer that returns organic waste to the agricultural produc- tion process and promotes soil fertility. To be used in agriculture, horticulture or gardening, compost must not contain substances harmful to plants or pathogens. If the compost is too young, or if the decomposition or storage process has not been controlled, phytotoxic substances can be formed in the compost.

Solution

The phytotoxicity of a compost can be tested using the open and closed cress tests. While the open cress test serves as a rough indicator, the closed cress test already indicates low com- post toxicity, as the seeds come into contact with the gases of toxic compounds emitted by the compost. As the open cress test alone does not always indicate healthy compost, it is advisable to always perform both tests.

Implementation checklist

Theme
Soil quality and fertility, nutrient availability, pest and disease control, weed control

Geographical scope
Where compost is available

Application date
Before using compost

Time required
1 hour / 5 days

Duration of effect
Crops fertilized with compost

Equipment required
Two containers, watercress seeds

Ideal use
For compost of dubious quality produced or purchased by the company

Benefits

Watercress reacts sensitively to substrate disturbances. Watercress tests are easy to perform and interpret, and require only readily available materials.

Procedure

- **Open cress test:** Fill a pot about 10 cm in diameter with a commercial universal substrate and a second pot with the compost to be tested.
- **Closed cress test:** Fill a worm or clear, sealable plastic container half-full with commercial universal substrate and a second container with the compost to be tested. Close containers tightly.
- Sow about 1g of cress per container, a little water and place the pots in a bright spot at room temperature (e.g. windowsill).
- After 5 days, compare plant growth in the two pots.

Left: Open cress test. Poorly developed cress in the pots in the bottom row indicates phytotoxic compost. Right: Closed cress test.
(Photos: Jacques Fuchs, FiBL, Frick)

Research Institute of Organic Agriculture FiBL. Determining compost quality using watercress tests. OK-Net Arable Conseil pratique.

Evaluation of the cress test

1. Open cress test (not very sensitive)

If after three days the mass of the plant in the pot in question is less than half that of the pot with garden soil, phytotoxic compost is present. If the compost is young, it should be reused and left to mature. If the compost is mature, it should be added to new compost so that substances harmful to plants can be broken down. Make sure that the compost reaches at least 70°C during decomposition.

2. Closed cress test (very sensitive)

If, after 5 days, the cress in the compost container has roots at least 70% longer than those of the cress in the garden soil, the compost can be used not only as a fertilizer for arable and vegetable crops, but also as a substrate for young plants and pots without hesitation.

Share results

Use the comment function on the Organic Farm Knowledge platform to share your experiences with other practitioners, consultants and researchers! If you have any questions about the method, please send an e-mail to the contact person.

For further information

Links

- At www.biophyt.ch, you'll find detailed information high-quality compost production in German, French and English.

About this practical tip and the OK-Net Arable project

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